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Environmental Science and Engineering, Inc, Gainesville, FL

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THE ECOLOGICAL EFFECTS OF ARSENIC EMITTED FROM NONFERROUS SMELTERS

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THE ECOLOGICAL EFFECTS OF ARSENIC EMITTED FROM NONFERROUS SMELTERS

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Final Report
Contract 68-01-3248, Task 1

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ABSTRACT

This report is an assessment of the ecological effects of arsenic and other associated contaminants emitted from nonferrous smelters on economically important plant and animal species in the human food chain. The objective of this study was to evaluate the latest information available on air, water, and solid waste discharges of arsenic and other heavy metals, along with sulfur oxide emissions from nonferrous smelters and associated ecological effects. To accomplish this objective, the study focused primarily on three areas of concern: (1) the extent of the ecological damage around primary and secondary smelters, both existing and closed; (2) the extent that arsenic, by itself or in combination with other chemicals, caused this ecological damage; and (3) how present or projected levels of emissions, including no discharge, affect the levels of damage.

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Northeastern Illinois Planning Commission

West Michigan Regional Planning Council

South Bend (Indiana) Area Planning Council

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I. Introduction

The following is an assessment of the ecological effects of arsenic and other associated contaminants emitted from nonferrous smelters on economically important plant and animal species in the human food chain. The assessment has relied on information gathered from appropriate state and federal authorities, and investigators knowledgeable in this area, as well as information taken from the available literature. The purpose of this assessment was to fully evaluate the latest information available on air, water, and solid waste discharges of arsenic and other heavy metals along with sulfur oxide emissions from nonferrous smelters and associated ecological effects. The following questions were addressed:

What is the extent of the ecological damage around primary and secondary smelters, both existing and closed?

To what extent is arsenic, by itself or in combination with other chemicals, the cause of this damage?

How will present or projected levels of emissions, including no discharge, affect the levels of damage?

In addition, general and resource information for most U.S. nonferrous smelters were compiled and are included to support the responses to these questions. The following are brief descriptions of the various subsections of the domestic nonferrous smelting industry:

Primary Zinc Industry

The domestic primary zinc industry is comprised of eight smelters (Figure 1) and includes electrolytic and pyrometallurgic plants. The latter are further divided into horizontal and vertical retorts (furnaces),

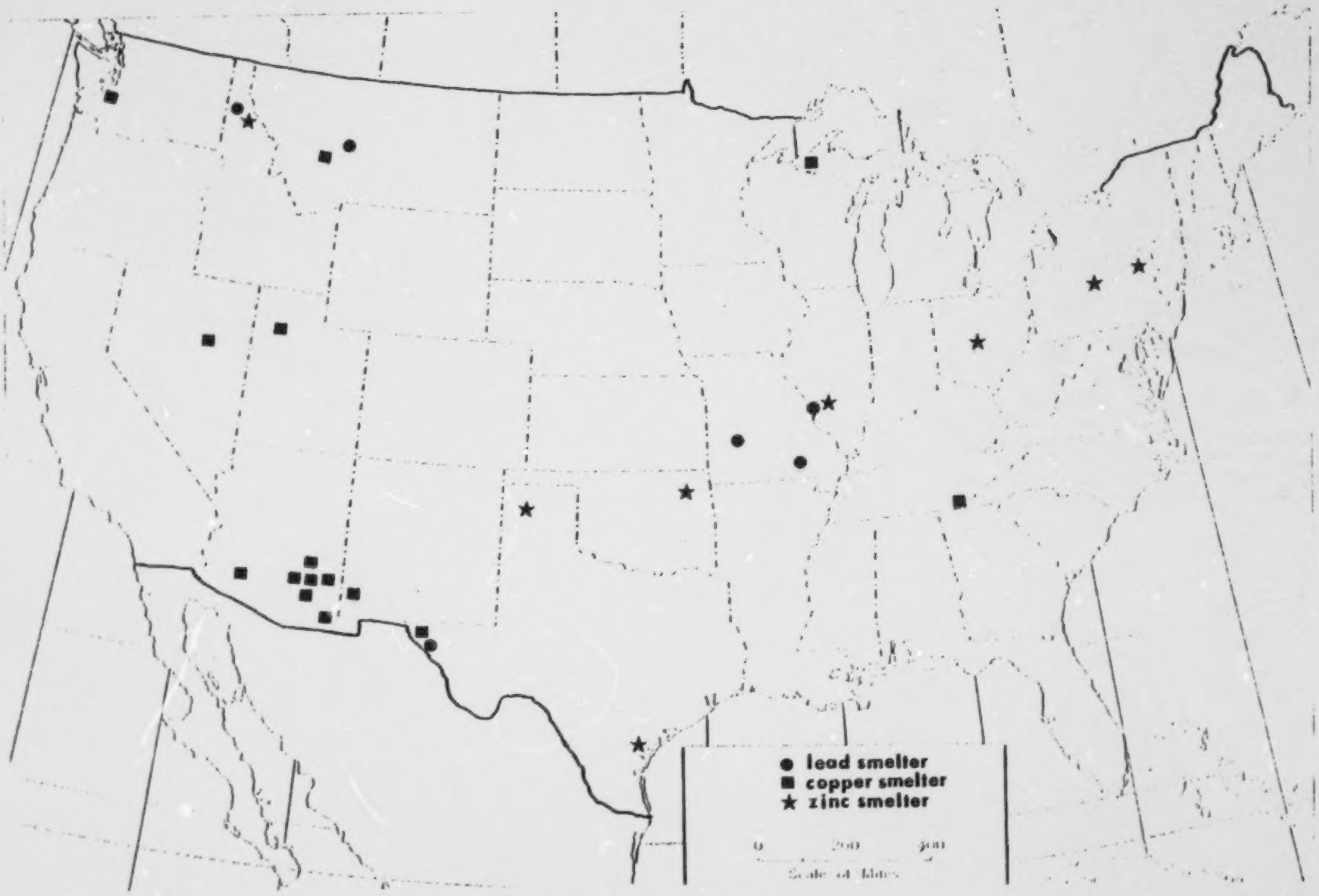

● lead smelter
■ copper smelter
★ zinc smelter
0
200
400
Scale of Miles

Figure 1. Existing domestic primary nonferrous smelters.

and horizontal retorts are generally smaller. Over half of the current domestic zinc metal production capacity is centered within the two large pyrometallurgical smelters in Pennsylvania. During 1969 to 1973 eight primary smelters were closed. Factors contributing to these closures included increased operating costs, inabilities to meet new environmental regulations, and/or depletion of local ore or energy supplies.

Plans to expand production include two new smelters—one in Tennessee and one in Kentucky which will come on line in 1978 or 1979. In addition, the old horizontal retort smelter of National Zinc (Bartlesville, Oklahoma) is being replaced with a new electrolytic plant (Rittenhouse, 1975). Other plans included the Amax purchase and reactivation of the electrolytic plant in Sauget, Illinois; ASARCO erecting a new plant in the Amarillo area; and ASARCO possibly expanding their Corpus Christi plant (Mining Journal, 1972 a and b). Additional information on existing primary smelters is presented in Table 1.

Primary Lead Industry

Five of the existing six domestic primary lead smelters are centered within the Missouri lead belt and the Coeur d'Alene lead area (Figure 1). There are no known new primary lead smelters under construction within the United States. All six smelters employ pyrometallurgical smelting and utilize sulfide ores which are either domestic or foreign in origin. Additional information pertaining to these smelters is presented in Table 2.

Primary Copper Industry

The fifteen existing primary copper smelters are centered in the southwestern portion of the United States (Figure 1). Seven of these

Table 1. Primary zinc smelters.

Company/Location	First Year	Type of Operation	Annual Production metric ton/yr	Products Produced	Last Modification
ASARCO Amarillo, Tx.	1976	New Facility	New Facility	New facility--not known	--
ASARCO Corpus Christi, Tx.	1942	Electrolytic	$9.8x10^4$	Slab zinc, zinc alloys, zinc sulfate, cadmium, sulfuric acid	1972 (changed flash to fluid bed roasting
Amax Sauget, Ill.	1974*	Electrolytic	$6.4x10^4$	Slab zinc, cadmium, zinc sulfate, sulfuric acid	--
Bunker Hill (Gulf Resources & Chemical Co.) Wallace, Id.	1928	Electrolytic	$1.1x10^5$	Slab zinc, zinc alloys, cadmium, sulfuric acid	1968 (second acid plant)
New Jersey Zinc (Gulf & Western Industries) Palmerton, Pa.	1899	Electrothermic	$1.0x10^5$	Slab zinc, zinc alloys, zinc oxide, cadmium, ferrosillican, mercury, sulfuric acid	--
St. Joe Minerals Corp. Monaca, Pa.	1938	Electrothermic	$2.3x10^5$	Slab zinc, zinc alloys, zinc oxide, cadmium, ferrosillican, mercury, sulfuric acid	--
National Zinc Co. Bartelsville, Ok.	1907	Horizontal Retort	$4.5x10^4$	--	1969 (acid plant)
ASARCO Columbus, Oh.	1967	ZnO plant	$9.5x10^4$	--	--

*Reactivated

Table 2. Primary lead smelters.

Company/Location	First Year	Type of Operation	Annual Production metric ton/yr	Products Produced	Last Modification
ASARCO Glover, Mo.	1968	Blast furnace smelting	1.4×10^5	Refined lead, copper dross, retort bullion	--
ASARCO East Helena, Mn.	1888	Blast furnace smelting	1.7×10^5	Lead bullion, soda ash matte, soda ash speiss, lead baghouse dust, zinc fume	--
ASARCO El Paso, Tx.	1887	Blast furnace smelting	--	Lead bullion, zinc fume	--
Bunker Hill Co. Kellogg, Id.	1917	Blast furnace smelting	5×10^5	Refined lead, gold, silver antimony	1971 (acid plant)
St. Joe Minerals Herculaneum, Mo.	1892	Blast furnace smelting	3×10^5	Refined lead, silver bullion, copper matte	1972 (new baghouse for fugitive emissions
Mo. Lead Operating Co. Boss, Mo.	1968	Blast furnace smelting	1.8×10^5	Refined lead, copper matte dross, silver bullion	--

domestic smelters are located in Arizona, while Washington, Utah, Texas, Tennessee, New Mexico, Nevada, Montana, and Michigan contain one primary copper smelter each. The local availability of copper ore in the southwest is responsible for this high density of copper extraction facilities in Arizona.

The basic process employed by the primary copper industry is pyrometallurgical. Primary copper smelters conventionally produce blister copper after roasting, smelting, and converting. In most cases, the blister copper is purified by fire-refining. If further purification is desired, an electrolytic process is used to produce cathode copper. Currently, there is one hydrometallurgical and four pyrometallurgical domestic primary copper smelters either under design, construction, or start up. Information on the name/location, age, process used, and products of each of these fifteen smelters is presented in Table 3.

Secondary Copper Industry

The secondary copper industry is the largest of all nonferrous secondary metals industries in the United States. Secondary production utilizes scrap metals or metallurgical wastes, whereas primary production utilizes ore concentrates. Presently, about 30 percent of the total U.S. copper demand is met by the secondary copper industry. The location of most of these smelters is centered either close to the source of the scrap or near inexpensive transportation. Thus, most of the secondary facilities are located within or adjacent to large urban areas. Additional information on these smelters is presented in Appendix A.

Table 3. Primary copper smelters.

Company/Location	First Year	Type of Operation	Annual Production metric ton/yr	Products Produced	Last Modification
Phelps-Dodge Morenci, Ariz.	1942	Copper concentrates to fluid-bed roaster, calcine to reverb, slag to dump, matte to converters. Blister copper to fire-refining.	$1.6\text{x}10^5$	Fire-refined copper, gold, silver, sulfuric acid	1964 (Roaster acid plant)
Kennecott Hayden, Ariz.	1958	Copper concentrates to fluid-bed roaster, calcine to reverb, slag to dump, matte to converters, anodes cast.	$7.3\text{x}10^4$	Blister copper	1968 (fluid-bed roaster and acid plant)
Cities Service Copperhill, Tenn.	1845 (Intermittent	Copper concentrates to fluid-bed roaster, calcine to electric furnace, slag water quenched, matte to converters.	$1.4\text{x}10^4$	Blister copper, shot copper, some copper chemicals	1972 (SO_2 treatment of electric furnace reverb gases)
Anaconda Anaconda, Mont.	1906	Copper concentrates dried in multiple-hearth roasters, fed to reverbs, slag granulated, matte to converters, blister copper fire-refined.	$1.8\text{x}10^5$	Fire-refined copper, sulfuric acid	1973 (new acid plant)
Kennecott Hurley, N.M.	1939	Copper concentrates to reverbs (green feed), slag to dump, matte to converter, blister copper fire-refined.	$8.4\text{x}10^4$	Blister copper, fire-refined copper, sulfuric acid, Mo	1971 (new fourth converter added)

Table 3. Continued.

Company/Location	First Year	Type of Operation	Annual Production metric ton/yr	Products Produced	Last Modification
Kennecott McGill, Nev.	1907	Copper concentrates to reverbs (green feed), slag granulated, matte to converters.	$3.9x10^4$	Blister copper, Mo	--
Kennecott Garfield, Utah	1907	Copper concentrates to reverbs (green feed), slag granulated, matte to converters, blister copper fire-refined, fire-refined copper electrolytically-refined to cathode copper.	$2.4x10^5$	Electrolytically refined copper, Mo, gold, Se, silver, sulfuric acid	1968 (Removed roasters and converted to green-feed reverbs)
Magma Sam Manuel, Ariz.	1956	Copper concentrates to reverbs (green feed), slag to dump, matte to converters, blister copper fire-refined, fire-refined copper electrolytically-refined.	$2.2x10^5$	Electrolytically refined copper, fire-refined copper, Mo, gold, silver, sulfuric acid	--
White Pine White Pine, Mich.	1955	Copper concentrates to reverbs (green feed), matte to converters, blister copper is fire-refined.	$1.3x10^5$	Blister copper, fire-refined copper, silver	--

Table 3. Continued.

Company/Location	First Year	Type of Operation	Annual Production metric ton/yr	Products Produced	Last Modification
Inspiration Miami, Ariz.	1915	Old: copper concentrates to reverb, matte to converters, some blister is electrolytically refined. New: copper concentrates to electric furnace, slag to dump, matte to syphon converters, blister copper fire-refined.	1.8×10^5	Blister copper, electrolytically refined copper, Mo, gold, silver, Se	1972 (elect. furnace, syph. conv., acid plant)
Phelps-Dodge Ajo, Ariz.	1950	Copper concentrates to reverb furnace, slag to dump, matte to converters, blister copper produced.	5×10^4	Blister copper, gold, silver, sulfuric acid	1972 (acid plants)
ASARCO El Paso, Tx.	1905	Copper concentrates roasted in multiple-hearth roasters, calcine to reverberatory furnace (reverb), slag is discarded on dump, and matte is charged to converters. Copper is cast into anodes.	9.1×10^4	Blister copper, gold, silver, sulfuric acid	1973 (new converter, acid plant under construction)
ASARCO Hayden, Ariz.	1912	Copper concentrates roasted in multiple-hearth roasters, calcine to reverb, matte to converters. Copper cast into anodes.	1.6×10^5	Blister copper	1971 (new converter acid plant)

Table 3. Continued.

Company/Location	First Year	Type of Operation	Annual Production metric ton/yr	Products Produced	Last Modification
ASARCO Tacoma, Wash.	1890	Copper concentrates roasted in multiple-hearth roasters, calcine to reverb, slag to dump, matte to converters, product blister copper. Electrolytic refining with approximately 1600 tanks.	$2x10^5$	Blister copper, elec. ref. copper, gold, silver, $NiSO_4$, As_2O_3, H_2SO_4, Liquid SO_2	1973 (liquid SO_2 plant for converter under construction)
Phelps-Dodge Douglas, Ariz.	1910	Copper concentrates roasted in multiple-hearth roasters, calcine to reverbs, slag to dump, matte to converters. Blister copper to fire-refining.	$1.3x10^5$	Blister copper as shot, fire-refined copper, gold, silver	1971 (new ESP on converters)

Secondary Lead and Zinc Industry

A more detailed list of domestic nonferrous smelters was recently compiled by the U.S. Bureau of Mines (Falkie, 1976) and is included as Appendix B. This compilation lists all domestic secondary zinc, lead, gold, tin, and copper smelters now in operation and also lists all zinc, lead, copper, and tin smelters closed since 1925. Unfortunately, these lists were not received in time to allow a survey of the resources and ecological damage existing within the environs of these facilities. Most of the secondary facilities are, however, located in industrialized areas, and, as such, should be of limited consequence to this study.

II. Summary

The following is an assessment of the degree of ecological damage which can be directly or indirectly associated with arsenic emissions from nonferrous smelters. Little damage near smelters has in the past been attributable to arsenic, whereas sulfur oxides, zinc, cadmium, copper, and/or lead have all been associated with significant ecological damage. Furthermore, land use within 10 miles of many of these smelters precludes extensive damage; that is, it is either land which has been taken out of production, supports naturally sparse vegetation and/or low numbers of livestock, and/or the crops commonly grown are resistant to arsenic. In addition, future levels of arsenic emitted from nonferrous smelters are expected to decrease as new sulfur oxide standards are imposed. Consequently, these lands most likely produce and will continue to produce an insignificant quantity of arsenic enriched food resources.

III. Conclusions

Ecological damage attributable to nonferrous smelters is directly related to the magnitude and duration of sulfur oxide emissions and/or with heavy metal loading of the neighboring ecosystem. In general, the extent and severity of this damage increases with approach to the source; and in most cases the local biota has been modified to reflect response to these perturbations. A continuum of responses to these perturbations has been reported which includes instances of no perceivable damage to almost complete loss of the biota from the contaminated area. In many instances, background conditions are reported to occur 10-15 miles from the smelter(s). Secondary impacts from these facilities include severe soil erosion, sedimentation with subsequent loss of topsoil, and contamination of natural waters.

Poor performance and/or loss of livestock associated with nonferrous smelter emissions does not appear to be a widespread problem; however, lead has been the metal most frequently linked with reported losses while arsenic and other heavy metals have less frequently been reported as either responsible or contributory. Most instances of livestock/smelter incompatabilities focus on farms or ranches located within five miles of the smelter. The probability and severity of damage to livestock, crops, or other biota increases with distance to the smelter and is directly related to such factors as: age, time of exposure, magnitude of exposure (acute-chronic), host stress, species differences, sex, general health, etc.

Ecological damage directly associated with arsenic emitted from nonferrous smelters with the exception of the Tacoma copper smelter is poorly documented. Both acceptable and nonacceptable levels of arsenic (based on Food and Drug Administration standards) have been found in foods and forage produced in close proximity to nonferrous smelters. Studies have shown that the amount of arsenic available for uptake by plants is dependent upon numerous soil properties, especially the iron and aluminum contents of the soil. In addition, most crops will contain less than 1 ppm arsenic even when grown in soils containing levels of arsenic which reduce yields to an extent where harvest is not economically feasible. Furthermore, those levels of arsenic toxic to animals are also toxic to plants and as such, sensitive and moderately sensitive crops usually fail in highly contaminated areas. Most importantly, biomagnification of arsenic through the human food reticulum apparently does not occur.

Wastewater discharged from nonferrous smelters has been reported to contain acceptable levels of arsenic. The potential for arsenic toxicity to occur in natural waters is limited since arsenic forms insoluble sediment complexes, becomes 60 times less toxic when oxidized, and is removed by municipal water treatment. Significant levels of arsenic and other heavy metals may enter surface and groundwaters as a result of mobilization of these contaminants from land-disposed smelter wastes and mine tailings. Since new air quality standards and process modifications will decrease atmospheric emissions of arsenic and other related contaminants, the amount of these toxicants in residues, slags, and collected flue dusts destined for land disposal will increase. Although most of these toxicants are believed to be insoluble, definitive studies are needed to quantify their mobility.

In conclusion, most of the acreage surrounding domestic nonferrous smelters provides crops and forage containing only slightly elevated levels of arsenic. The role of arsenic as a toxicant appears to be of minor consequence compared to that of lead, cadmium, zinc, copper, and oxides of sulfur. Fortunately, present land use around most smelters precludes or reduces damage to the local biota from arsenic and these related contaminants. Lands adjacent to most nonferrous smelters probably produce and will continue to produce insignificant quantities of food resources and, as a result, will contribute insignificant quantities of heavy metals to the human diet.

IV. Recommendations

The following three recommendations are based on the results of this assessment:

(1) The levels of arsenic and related heavy metals entering the human food chain from crops and livestock produced near smelters that have been closed are expected to pose no threat to human health. In areas where smelters are fully operational, however, deposition of airborne emissions and fugitive dust from smelting and/or mining activities along with plant uptake of these contaminants from the soil may significantly contribute to contamination of foodstuffs. Conflicting reports of the acceptability of foodstuffs produced near these smelters warrants further field study.

(2) Land disposed slags, sludges, and collected flue dusts constitute the major process loss of arsenic and related heavy metals. These wastes are of varying form and concentration of contaminants, and when deposited in severely eroded or denuded watersheds, the potential for runoff, leaching, and sediment transport of heavy metals and arsenic is high. Studies are warranted to determine the extent of dispersion of these wastes from disposal areas and to determine if regulations need to be promulgated to ensure environmentally adequate disposal.

(3) Several instances of severe erosion have been reported near nonferrous smelters coupled with excessive sedimentation of neighboring reservoirs or lakes. The productivity and water quality of these lakes along with the levels of arsenic and other related contaminants in aquatic resources needs to be determined and warrants field study.

V. The Extent of Ecological Damage Around Smelters

Ecological damage resulting from nonferrous smelting and refining has been documented by many workers. Much of this damage has been directly linked to sulfur dioxide emissions and/or heavy metals dispersed to the neighboring environs. The following is a brief synopsis of the literature:

A lead smelter in Canada was reported by DeKoning (1974) to be contributing significant quantities of lead to the environment (exceeded 2 $\mu g/m^3$ lead in air 10 to 20 percent of time). DeKoning concluded that these levels pose a threat to livestock which graze within this area. The smelter was found to contribute only a small amount of cadmium and no cadmium pollution was directly attributable to the smelter.

Vegetation damage within Lehigh Gap, Pennsylvania, was linked to extremely high (and toxic) levels of zinc and cadmium emitted from two primary zinc smelters (Buchauer, 1973). Past forest fires and subsequent soil erosion have also contributed to the problem.

Elevated levels of zinc, lead, cadmium, nickel, and iron were found in leafy vegetables grown in close proximity to an Australian copper smelter (Beavington, 1975). In addition, sparse and poor growth of clover were associated with soil copper levels (Beavington, 1973 and 1975).

Little and Martin (1972) reported considerable contamination of vegetation and soil by zinc, cadmium, and lead near a smelter in the Avonmouth area (Great Britain). Background levels were approached five to ten miles from the smelter. They noted higher levels in forest soils than in agricultural soils which they associated with decomposition of leaf litter rich in these metals. Plowing was also mentioned as a possible contributor to the lower levels found in agricultural soils.

Much of the obvious damage to vegetation in the vicinity of the Tacoma smelter has in the past been associated with sulfur dioxide emissions. More recently, Ratsch (1974) and Crecelius, Johnson, and Hofer (1974) have reported elevated levels of copper, arsenic, cadmium, lead, and antimony up to six miles from this smelter; and Ratsch (1974) reported levels of copper, arsenic, and cadmium high enough to affect the growth and establishment of plants, and levels of cadmium and mercury in leafy vegetables potentially hazardous to health. Levels of lead and arsenic in milk and blood from dairy cattle within 15 miles of the Tacoma smelter were found to be relatively low and did not suggest excessive exposure (Orheim, Lippman, Johnson, and Bovee, 1974). The average arsenic content of hair of these exposed cows, however, was about twice that of cows from the control area (located about 30 miles from the smelter).

Significant damage from sulfur dioxide fumigations has been reported throughout the Sudbury, Ontario, mining and smelting region by Hutchinson (1975), Gorham and Gordon (1960a and 1960b), Linzon (1972), and Whitby and Hutchinson (1974). In 1970 alone, over 2100 square miles of forest were damaged in the Sudbury region by sulfur dioxide (Hutchinson, 1975). A recent study by Whitby and Hutchinson (1974) reported soil levels of copper and nickel within 6.5 miles of these smelters which are inhibitory to seedling establishment and subsequent revegetation. They concluded that as sulfur dioxide emissions are reduced, revegetation will be impeded by the high levels of these metals presently in the soil. Hutchinson and Whitby (1974) also reported elevated levels of nickel and copper in biota, water, and sediments of a nearby river-lake system.

In a study conducted near the previous site of the zinc smelter in Henryetta, Oklahoma, Pancholy, et al. (1975) found that most of the 1000 acres which lacked vegetation in 1953 were still bare. They also found a much reduced number of soil microorganisms in this area, along with elevated levels of soil zinc and cadmium.

The Copper Basin area of Polk County, Tennessee, best exemplifies the slow recovery of an area damaged by smelting activities. Late nineteenth century smelting practices (heap roasting) not only emitted copious quantities of sulfur dioxide at near ground level, but also relied heavily on timber and later stumps for fuel. Severe soil erosion followed and the combined perturbations on neighboring woodlands soon resulted in the denudement of 50 to 100 square miles (Cities Service Company, 1973). Presently much of this acreage remains barren.

The Silver Valley of northern Idaho (Kellogg-Smelterville area) has also experienced severe vegetative loss and soil erosion associated with sulfur dioxide fumigations from smelters (Miller, et al., 1975). The problems in the Silver Valley are further amplified by sedimentation of Lake Coeur d'Alene, with tailings high in arsenic, cadmium, and lead content. Reservoirs in the Copper Basin area are also experiencing similar sedimentation problems (see the resource inventory for the Cities Service Copper Smelter, Appendix A, for further details).

Numerous instances of heavy metal/livestock incompatabilities in the vicinity of nonferrous smelters have been reported. The following is a brief review of the more noteworthy studies:

Lead poisoning of horses has been documented within 6.5 miles of the Trail, Canada, lead smelter; within the "smoke zone" of the Selby, California, lead smelter (Knight, 1973); and within two miles of the lead smelter in St. Paul, Minnesota (Hammond and Aronson, 1963).

In Montana, loss of cattle production within 10 miles of the copper smelter in Anaconda has been reported (Gordon, 1976; Swain and Harkins, 1908), while sheep may not be pastured within 10 miles of the ASARCO lead smelter in East Helena (EPA, 1972). Furthermore, horse raising has not been feasible near this ASARCO smelter for 15 years.

Studies conducted on the zinc, cadmium, copper, and lead contamination of man's food chain as a result of mining and smelting activities in southeastern Missouri (University of Missouri Study, 1972) identified the main sources of heavy metals contributing to heavy metal contamination of forage and cattle to be smelter stack emissions, truck spillage of ore concentrates, and fugitive dusts from ore stockpiled around the smelter. Incidents of horse deaths in the area were attributed to lead contamination of forage. Levels of lead in forage were tolerable to cattle grazing in the area of the smelter.

Cattle grazed within one mile of the Blackwell zinc smelter were reported to experience significant weight loss due to the ingestion of forage which contained non-tolerable levels of zinc, lead, and arsenic (Benenati, 1974). In addition, there is a record of one horse death in the area which was associated with toxic levels of zinc and lead in forage (Benenati and Risser, 1972). This pasture was located four miles north of the Blackwell smelter.

Livestock loss related to heavy metals occurred near the Magma copper smelter when livestock utilized water and pasture irrigated by water which had run through a tailings disposal area (Lamoreaux, 1975). Water levels were low at the time, and as a result contaminants were concentrated by evapotranspiration. The tailings water was from a neighboring operation which has since closed.

Although no crop damage has been noted in the vicinity of the Eagle-Picher zinc smelter (Galena, Kansas), litigation occurred against the smelter in the early 1970's due to alleged livestock damage (Brower, 1976). The Agricultural Research Service subsequently investigated the heavy metal content of soils, crops, natural vegetation, cattle, milk, and human blood and hair collected from the region (Lagerwerff, Brower, and Biersdorf, 1973; Lagerwerff and Brower, 1974). In some instances, grass and forage crops were found to exceed potentially toxic zinc and lead levels for cattle. Samples were not analyzed for arsenic content.

An area three to five miles downwind of the Eagle-Picher zinc smelter (Henryetta, Oklahoma) presently cannot be utilized for raising either young colts or clover (Worthy, 1976). This smelter was closed in 1969.

The poor performance and death of livestock grazing in proximity to smelters has been a potential problem near many smelters (Schmitt, et al., 1971; University of Missouri Study, 1972; Hammond and Aronson, 1963; Benenati and Risser, 1972; and Knight and Burau, 1973). In general, horses have been found to be more susceptible to smelter emissions than cattle, while lead has been the most responsible heavy metal for livestock loss. Additional reports of ecological damage to vegetation and livestock are presented in the resource inventories which were compiled for each of the major nonferrous U.S. smelters (Appendix A).

Ecological damage directly related to arsenic near nonferrous smelters is poorly documented. A recent study by Temple, Linzon, and Chai (1975) reported elevated levels of arsenic in trees and shrubs, grass, and soil associated with two secondary lead smelters in southern Ontario, Canada (Table 4). No visible damage to vegetation could be associated with arsenic even for vegetation growing near these smelters in soils containing 1500 to 2000 ppm arsenic. Fresh fruit and vegetables were found to contain less than 1 ppm arsenic; levels below Canadian standards for fruits and vegetables. Studies sponsored by the U.S. EPA reported that unwashed vegetables and crops grown within a four mile radius of the East Helena smelter caused levels of arsenic within acceptable limits set by the Food and Drug Administration (EPA, 1972). For comparison, vegetables grown within a five mile radius of the Trail lead smelter (Canada) contained up to 3.0 ppm arsenic, while root vegetables contained up to 7.3 ppm (Schmitt, et al., 1971), and a study conducted by Ratsch (1974) identified levels of arsenic toxic to sensitive and moderately sensitive plant species in soils near the Tacoma smelter. In addition, damage to peach trees within the Tacoma area was linked with both sulfur dioxide and arsenic emissions from this smelter. Crecelius, Johnson, and Hofer (1974) reported elevated levels of soil arsenic up to six miles from this smelter. Emphasis should not be placed on these Tacoma area studies, since the Tacoma smelter is the only U.S. smelter producing commercial arsenic and having a deep water port. The port facility allows the smelter to import about 30% of its ores from South America and the Philippines. These ores (5.2% arsenic) are higher in arsenic content than most U.S. ores (less than 0.2% arsenic).

Table 4. Arsenic content (ppm dry weight) of samples collected near two smelters and an urban area (after Temple, Linzon, and Chai, 1975).

Sample		Urban Control Area	Smelter A	Smelter B
Trees & shrubs (unwashed)	Mean	0.9	7.4	2.45
	Range	0.4-1.3	0.9-33.4	0.4-12.7
Grasses (unwashed)	Mean	0.7	5.8	3.23
	Range	0.4-1.2	0.3-62.1	0.5-49.0
Soil (0-5 cm)	Mean	9.8	107	35
	Range	2.7-40.7	4.7-2005	2.6-248

The El Paso and Anaconda copper smelters also process high arsenic content ores (0.96 and 0.8% arsenic, respectively). All other domestic primary copper smelters process ores containing less than 0.2 percent arsenic, while primary lead and zinc smelters process ores containing less than 0.1 percent arsenic (EPA, 1975). Based on production and arsenic content of the concentrates processed the Tacoma, El Paso, and Anaconda smelters should be prime examples of arsenic contamination of the neighboring environs. As mentioned previously, Crecelius, Johnson and Hofer (1974) reported elevated arsenic levels up to six miles from this smelter. In addition, Price (1975) reported that the El Paso area probably had the highest concentrations of arsenic in Texas, while Nimlos (1976) reported adverse effects to lodgepole pine and white spruce seedlings grown within ten miles of the Anaconda facility. For comparison, Benenati (1974) reported soil levels of arsenic which were high enough to cause significant agricultural loss within one to three miles of the Blackwell site. Sampling occurred while the Blackwell smelter was fully operational. In general, the results of these studies suggest that the rate of production of sensitive and moderately sensitive plants (e.g., alfalfa, soybeans, etc.) is extremely affected by arsenic contamination within an area of a one to ten mile radius of most domestic primary smelters. The size of this area for a particular smelter is not only dependent on emission parameters such as the amount of arsenic in the ore, or the amount of ore processed, but also on such factors as soil properties, land use, and complemented stresses (e.g., fire, presence of other heavy metals — cadmium, copper, and zinc -- soil erosion, sulfur dioxide damage, etc.).

VI. Cause of Damage

Overall, damage related to arsenic appears of minor importance when compared to damage from other heavy metals and/or sulfur dioxide emissions from nonferrous smelters. Present land use around most U.S. smelters precludes or reduces damage to locally produced foodstuffs from arsenic and related contaminants for the following reasons:

(1) Many smelters are located in the southwest and are surrounded by sparse natural vegetation capable of supporting low livestock levels.

(2) Most smelters lack arsenic sensitive crops within a five mile radius of the facility. In some instances this lack may be due to soil arsenic levels and/or other heavy metals (Ratsch, 1974; Beavington, 1973; and Benenati, 1974).

(3) Agricultural practices (i.e., plowing, liming) have been shown to reduce soil levels and availability of arsenic and other heavy metals such as zinc, cadmium, lead, and copper.

(4) Many smelters are surrounded by mines and/or company-owned lands which have been taken out of agricultural production.

(5) Poor gains or past losses in a marginally profitable endeavor will minimize the number of smelter-area farmers/ranchers who produce foodstuffs within these highly contaminated areas.

The limited reported occurrence of arsenic related damage in the environs of nonferrous smelters may, however, reflect past emphasis of researchers on studying those metals most easily analyzed (zinc, copper, lead, tin, cadmium, and nickel). One expects the major heavy metal contaminants dispersed throughout the environs of these smelters to reflect the composition of the ores processed. For example, Hutchinson and Whitby (1974) were able to associate copper and nickel soil levels with poor seedling establishment, whereas zinc and molybdenum, which are not presently smelted in Sudbury, showed very limited evidence of soil loading. Relative toxicities of the various metals must also be considered.

For arsenic sensitive species, damage may occur at soil levels which are found throughout an extensive area (Tacoma Study, Ratsch, 1974), while other less toxic metals may be commonly found in higher concentrations. The situation is further complicated when levels of zinc and cadmium or other heavy metals are found which are toxic to the existing crop, while arsenic levels are not high enough to be problematic. Subsequent planting of a different crop which is sensitive or moderately sensitive to arsenic could reverse the importance of these metals with arsenic being the limiting factor. In the Blackwell, Oklahoma area, for example, wheat was found to be affected by zinc and cadmium levels within one-half to three-quarters of a mile from the smelter; however, present land use precludes much economic loss. If acreage within three miles of this plant was replanted to alfalfa or some other arsenic sensitive crop, economic loss would possibly result related to non-tolerable arsenic soil levels.

Many food plants are sensitive to soil arsenic and show significant yield reduction when grown in soils containing non-tolerable levels of arsenic (Table 5). Soils treated with arsenical pesticides contain from 1.8 to 830 ppm arsenic; untreated soils usually contain from 0.5 to 14 ppm (Woolson, Axley, and Kearney, 1971). The presence of a given level of arsenic in the soil, however, does not preclude a phytotoxic response since the amount of plant available (soluble) arsenic is greatly influenced by a number of soil properties. In fact, under certain soil conditions the addition of arsenic to a soil has been found to stimulate growth of some plants (Stewart and Smith, 1922; Cooper et al., 1932; Jacobs, Keeney, and Walsh, 1970).

Table 5. Toxic levels of soluble As to various crops and vegetables.

Plant	Toxic level soluble As (ppm)	Reference
cowpeas	1	Albert and Arnt, 1931
barley	2	Vandecaveye, 1943
snap beans	2.5*	Jacob et al., 1970
peas	2.5	Jacob et al., 1970
	9*	Bishop and Chisholm, 1962
alfalfa	3.4-9.5	Vandecaveye et al., 1936
soybeans	3-12	Deuel and Swoboda, 1972
rice	7	Epps and Sturgis, 1939
cotton	8-28	Deuel and Swoboda, 1972
beans	9	Bishop and Chisholm, 1962
corn	20*	Jacob et al., 1970
potatoes	37*	Jacob et al., 1970
green beans	10-50*	Woolson, 1973
lima beans	10-50*	Woolson, 1973
spinach	10-50*	Woolson, 1973
tomatoes	50+*	Woolson, 1973
radish	50-100*	Woolson, 1973
lowbush blueberry	84.5	Anastasia and Kender, 1973
cabbage	100+*	Woolson, 1973

*level which produces 50 percent yield reduction

In general, plants grown on finer textured soils are less affected by a given level of arsenic soil loading (Woolson, Axley, and Kearney, 1971; Jacobs, Keeney and Walsh, 1970; and Deuel and Swoboda, 1972). This relationship is related to the higher clay content and the associated richer iron, aluminum, calcium, and magnesium content of these finer textured soils.

With the exception of root crops, most crops will contain less than 1 ppm arsenic even when grown in soils containing levels of arsenic which cause a 50 percent reduction in yield (Woolson, 1973). The Food and Drug Administration has set allowable limits of arsenic in foods for interstate commerce at 2.6 ppm. Since most crops which suffer a 50 percent reduction in yield cannot be economically harvested, Woolson (1973) concluded that crops grown in soils containing levels of arsenic which result in a 50 percent growth reduction would be indicative of the maximum arsenic content of plants grown on contaminated soils. Woolson (1973) reported very low levels (usually less than 1 ppm) of arsenic in the edible portions of all but the root crops he tested under 50 percent growth reduction conditions. The significance of these findings pertain to crops grown in the environs of smelters that are no longer in operation. Around these facilities, soil contamination is the most significant source of arsenic to vegetation and the human food chain. Based on Woolson's (1973) studies, forage and crops produced in these areas should be fit for consumption.

In areas where smelters are operational, deposition of airborne emissions and fugitive dusts from smelting and/or mining activities are expected to significantly contribute to foodstuff contamination. In support of this premise, leafy vegetables grown within 1 mile of the Trail smelter contained 3 ppm arsenic (Schmitt et al., 1971); and leafy vegetables grown within 1 mile of the Tacoma smelter contained 57 ppm arsenic (on the average), while those within 1 to 5 miles contained 5 ppm arsenic (on the average) (Feigner, 1975). Not all operational smelters, though, are surrounded by fields which produce leafy vegetables and/or crops which exceed the Food and Drug Administration standard. Studies by Temple, Linzon, and Chai (1975), EPA (1972), and Benenati and Risser (1972-73), and Benenati (1974) reported acceptable levels of arsenic in vegetables and/or crops grown near fully operational nonferrous smelters.

Market basket studies conducted by Schroeder and Balassa (1966) and The Bureau of Foods (1975) were reviewed in order to evaluate the significance of the elevated arsenic levels of foodstuffs produced near operational smelters. Schroeder and Balassa (1966) reported that terrestrial foodstuffs usually contain less than 0.5 ppm arsenic while seafoods usually meet or exceed the Food and Drug Administration Standard of 2.6 ppm (fish 2 to 8 ppm; oysters 3 to 10 ppm; mussels and shrimp 42-174 ppm arsenic). They concluded that the daily intake was dependent upon seafood consumption and estimated daily intake levels from 400 to 1000 μg/day. The Bureau of Foods Study (1975), which was representative of the contiguous United States, estimated the daily intake level of arsenic to be 10 μg/day. The consumption of foodstuffs produced near domestic non-ferrous smelters then should not be hazardous to one's health as these foods contain no more arsenic than seafoods. In addition, arsenic in foods has not been shown to be carcinogenic.

Another important consideration, especially for closed smelters, is residency time of the various heavy metals in soils. Studies in the

United States and Europe relating heavy metal toxicity, persistence, and accumulation in soils associated with smelter operations have shown that natural revegetation of denuded areas adjacent to closed smelters usually does not occur within 70 years (Whitby and Hutchinson, 1974). Bowen (1975) estimated the following residency times: for arsenic, 2000 years; for zinc, 2000+ years; for lead, 3000+ years; and for cadmium, 200 years. Based on these estimates, arsenic will remain a soil contaminant longer than cadmium. Soil lead is of limited concern to most plants due to its limited uptake by roots.

As mentioned in the first section of this assessment, damage to vegetation from sulfur dioxide emissions from nonferrous smelters has been documented and continues to be of concern. The severity of the damage from sulfur dioxide near United States smelters has been reduced by forced shutdowns or control measures (acid plants and/or scrubbers). Secondary effects from sulfur dioxide damage, such as severe soil erosion, will persist for thousands of years after smelter closure.

Arsenic losses to the atmosphere during the processing of ore concentrates account for 14 percent of the total arsenic originally in the concentrates used for copper smelting, 22 percent of that used for lead smelting, and 36 percent of that used for zinc smelting. However, eleven times more arsenic is emitted to the atmosphere by the domestic copper industry (4800 kkg/yr) than from both the lead (240 kkg/yr) and zinc (190 kkg/yr) industries combined. For comparison, arsenic losses destined for direct land disposal account for 62 percent of the total arsenic originally in the copper ore concentrates, 75 percent of the total arsenic in lead concentrates, and 23 percent of the arsenic in the zinc concentrates. Whereas, there is twentyfive times more arsenic disposed to land as a result of copper smelting (21,800 kkg/yr) than from both the lead (800 kkg/yr) and zinc (120 kkg/hr) industries combined. Arsenic losses during processing are summarized in Table 6. Land is the major receptor of these losses. When deposited within severely eroded or denuded basins (such as Coeur d'Alene, Copperhill, and Lehigh Gap) the potential for runoff, leaching, and sediment transport of heavy metals is high. Smelters in the arid Southwest are less affected by this problem; however, strong winds may act to disperse tailings and residues over extensive areas (Voget, 1975). Dusts from ore and/or residue piles along with tailings from nearby mining activities have been reported to significantly contribute to soil/plant heavy metal loading (Benenati, 1974; Miller, et al., 1975; Gorham and Gordon, 1960a; Buchauer, 1973; and Missouri University Study, 1972). Most fallout is expected to occur within the first 1/4 to 1/2 mile downwind of the source and, as such, most environmental loading will occur within this area.

The physiological role of these dusts to vegetation are minimal, though there may be limited uptake through plant stomates. Of major significance is the contribution of these dusts to forage, especially during winter when forage metal levels (lead, cadmium, and zinc) may reach toxic concentrations (Schmitt, et al., 1971; Hammond and Aronson, 1963; Knight and Burau, 1973; and Benenati, 1974).

In areas free of gross pollution, the ambient atmospheric arsenic concentration is in the range of 0-10 ng/m^3 (Braman, 1975). However,

Table 6. The distribution of the arsenic originally in zinc, lead, and copper concentrates (EPA, 1975).

Zinc Concentrates		
Loss to Atmosphere		190 kkg/yr
Retained in Zinc Products		5 kkg/yr
In-Land-Destined Wastes		120 kkg/yr
In Wastewater Effluents		0.4 kkg/yr
In Residues Shipped to Lead Smelter		210 kkg/yr
	Total	525 kkg/yr
Lead Concentrates		
Loss to Atmosphere		240 kkg/yr
Retained in Refined Lead		20 kkg/yr
In Land-Destined Wastes		800 kkg/yr
	Total	1,060 kkg/yr
Copper Concentrates		
In Lake Copper Product		30 kkg/yr
In Fire-Refined Copper Product		6 kkg/yr
In Electrolytic Copper Product		7 kkg/yr
In Slags to Land Disposal		1,900 kkg/yr
In Sludges to Land Disposal		1,500 kkg/yr
In Flue Dusts to Land Disposal		9,600 kkg/yr
In Leach Residues to Land Disposal		8,800 kkg/yr
In Treated Wastewaters		32 kkg/yr
In Air Emissions		4,800 kkg/yr
In Commercial White Arsenic		8,300 kkg/yr
	Total	35,000 kkg/yr

ambient arsenic concentrations of up to 20 μg/m^3 have been reported for the vicinity of the copper smelter near Tacoma (Roberts, 1975). Atmospheric contamination by arsenic in the Seattle area from this smelter is further reflected by an average value of 17 ± 8 μg/l in unfiltered rain and snow as compared with a value of 0.4 ± 0.2 μg/l in an area remote from the source of pollution (Crecelius, et al., 1975). Dust samples collected by high volume sampler 25 miles downwind of this smelter contained arsenic concentrated to greater than 2000 ppm (Crecelius, et al., 1974). This data for the Tacoma-Seattle area indicates washout by rain and snow and dry fallout are two mechanisms responsible for removal of arsenic containing materials from the atmosphere.

The current estimate of particulate stack emission for the ASARCO Tacoma copper smelter for 1975 is 150 tons/yr composed of 53 percent arsenic trioxide (Nelson and Roberts, 1975). The estimated 80 ton emission of arsenic trioxide at the ASARCO smelter clearly provides sufficient justification to regard this smelter as a major arsenic polluter. If pollution control equipment at other nonferrous smelters is operated at least as effectively as the ASARCO smelter, the above values could be expected to provide upper limits for arsenic pollution associated with nonferrous smelter stack emissions, as the copper ore processed at Tacoma contains the highest arsenic content (5.2 percent) of any ore processed in the United States (Carapella, 1964).

A brief consideration of normal operating conditions can provide insight concerning stack emissions. As flue gases normally possess a high moisture content, an efficient application of baghouse and electrostatic precipitator collection techniques to reduce heavy metal emissions necessitates high-temperature operation. At the Tacoma smelters the flue dust is further processed to reclaim arsenic trioxide. Although the Tacoma smelter is the only facility involved in commercial production of arsenic trioxide, such recycling procedures to reclaim heavy metals at other nonferrous smelters are common and provide an additional opportunity for release of arsenic to the atmosphere.

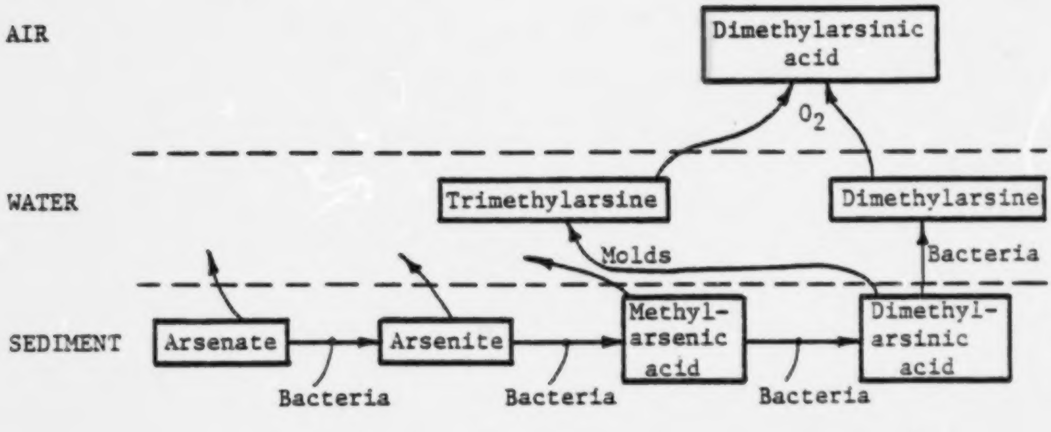
Based on a survey of the major existing and closed domestic nonferrous smelters, poor performance and/or loss of livestock does not appear to be a widespread problem. In those instances where losses have been reported (see Section V), lead has been the metal most associated with the loss. Arsenic and other metals have also been reported as either contributory or responsible for the loss.

Arsenic levels in the surface waters and drinking water supplies of the United States have increased over the past 30 years, and it is believed that much of this increase is due to non-natural arsenic containing sources such as detergents, pesticidal runoff, and leachings from excavations and mining operations (EPA, 1975). In a 1970 survey of 150 rivers in the United States, approximately 7 percent of the 1500 samples exceeded the U.S. Public Health Service recommended maximum drinking water concentration of 10 ppb (0.01 mg/l) (Ferguson and Gavis, 1972). The mean arsenic concentration of samples exceeding the 10 ppb limit was 100 ppb, or ten times the recommended maximum concentration and twice the maximum permissible concentration. In a similar survey in 1971, 21 percent of 727 samples from rivers and lakes in the United States had arsenic contents above the 10 ppb limit (Ferguson and Gavis, 1972). Most estimates for mean arsenic levels in seawater have been below 20 ppb, with some being as low as 2-3 ppb (Sullivan, 1969; Lansche, 1965; Schneider, 1971; and Ferguson and Gavis, 1972).

Direct waterborne effluents of arsenic from primary zinc, lead, and copper smelters are relatively small, with the total waterborne loss of arsenic by each industry (1974 basis) being 0.4, 0, and 32 kkg/yr, respectively (EPA, 1975). Studies conducted by the Effluent Guidelines Division of EPA (EPA, 1975 a, b, and c) report the following for total discharge of arsenic: from primary zinc smelters 0.1 to 0.68 mg/l; from primary lead smelters 0.01 mg/l; and from primary copper smelters 0.001 to 0.174 mg/l. Proposed U.S. water quality standards (EPA, 1972) set the following levels of arsenic as acceptable: 0.1 mg/l or 2.0 mg/l for 20 years acceptable for irrigation; 0.2 mg/l acceptable for livestock consumption; and 0.01 mg/l (10 ppb) acceptable for public water supplies. Assuming no dilution of these discharge waters, the effluent in most cases is fit for agricultural use without further treatment; while with a 10-fold dilution or greater, the effluent should in most cases be fit for human consumption without further treatment. Although these amounts in themselves may not be overly important in regards to surface water contamination, the possibility of contamination of surface and groundwaters by land-disposed smelter wastes should not be overlooked. The arsenic content of land-destined wastes for the primary zinc and lead industries is 120 and 800 kkg/yr, respectively (EPA, 1975). In the primary copper industry, where 50 percent of the arsenic in copper ore concentrates resides in slags, sludges, waste flue dusts, and acid plant residues (all of which are eventually disposed of on land), the total arsenic content of land-destined wastes is 21,800 kkg/yr (EPA, 1975). Although much of this arsenic may be in insoluble forms, definitive studies are still needed on the amounts and rates of arsenic and other heavy metals transported from the waste disposal sites to the surrounding environment.

Generally speaking, arsenic is of limited potential toxicity in natural water bodies because: 1) arsenic is usually locked into insoluble sediment complexes or immobilized in soil, 2) arsenic becomes ten to sixty times less toxic when oxidized from the trivalent to the pentavalent form, and 3) municipal water treatment can effectively reduce arsenic to acceptable limits (EPA, 1975). Although arsenic levels in drinking water sometimes exceed established standards, the concentrations and forms of arsenic encountered are believed to pose little threat to public health (EPA, 1975).

A biological cycle for arsenic in water is presented below (EPA, 1975):


AIR
Dimethylarsinic acid
O_2
WATER
Trimethylarsine
Dimethylarsine
Molds
Bacteria
SEDIMENT
Arsenate
Arsenite
Methyl-arsenic acid
Dimethyl-arsinic acid
Bacteria
Bacteria
Bacteria

As already mentioned, arsenate becomes 10-60 times less toxic as oxidation occurs to arsenate. There is evidence that another great reduction in toxicity occurs with methylation where the methylarsines are in solution or contained in the tissues of aquatic organisms. This is in contrast to the extreme toxicity of methylarsines in the gaseous state.

Studies have indicated that inorganic arsenic compounds (arsenates and arsenites) may be toxic to a variety of aquatic organisms at levels as low as 0.5 to 5.0 ppm (Becker and Thatcher, 1973). However, bioaccumulation of organic arsenic compounds (methylarsines) by aquatic organisms is common, sometimes resulting in tissue concentrations of arsenic tens of thousands times higher than ambient levels (Ferguson and Gavis, 1972; Reay, 1972; Vallee et al., 1960; Braman and Foreback, 1973; and Woolson, 1975). It is for this reason that seafood is considered to be one of the main sources of arsenic for people unexposed to industrial sources. The ingestion of such seafoods has generally presented no hazard to human health, the arsenic usually being in a form which is rapidly metabolized and excreted. Biomagnification of arsenic (increasing tissue levels at higher positions up the food chain) apparently does not occur (Ferguson and Gavis, 1972; Reay, 1972; Vallee et al., 1960; and Woolson, 1975).

In summary, the main hazard of arsenic in water is evidently not through the eating of arsenic-containing seafood (except perhaps in areas with extremely high levels of arsenic contamination) or in the drinking of waters containing normal amounts of arsenic compounds, but in the drinking of waters contaminated with high levels of inorganic trivalent arsenic (arsenates) (EPA, 1975).

The levels of arsenic, zinc, lead, and cadmium that are toxic to livestock are summarized in Tables 7 through 10. The toxic action of these metals has been shown to be influenced by age, sex, exposure time, host stress, general health, physical condition, season, feed additives, digestive tract acidity, stage of pregnancy and lactation, species differences, and the source of the metals. In addition, the following factors may also effect the toxic action of these metals:

Cadmium and lead are less toxic to animals that have simultaneously consumed high levels of zinc (Pond, et al., 1966; Powell, et al., 1964; and Willoughby, et al., 1972 a and b).

Since animals (especially sheep) may be selective grazers, and since the metal content of forage changes seasonally, the amounts of these metals consumed by an animal might not be equivalent to the reported average concentrations of these metals in a given field (Allcroft and Blaxter, 1950).

Livestock have been shown to be more readily poisoned by contaminated vegetation than by feed supplemented with metals (Willoughby, et al., 1972 a and b, and Kradel, et al., 1965).

The concentrations of these metals reported in the literature can be used to delineate areas around smelters that are potentially safe for grazing by livestock; however, the previously mentioned factors (age, sex, feeding habits, etc.) might make a potentially safe pasture unsafe or vice versa.

The potential for poor dispersion of emissions of both sulfur dioxide and particulates from nonferrous smelters is related to topographic and meteorological conditions at the smelter site. Poor site

Table 7. Potentially toxic arsenic levels for livestock.

Test Animal	Daily Feed Intake (Dry Weight)	Author
Cattle:		
Holstein - type lactating cows	1.25 mg As/kg body wt daily as Arsenic acid for 8 wk not toxic (equal to about 60 ppm As in forage)	Peoples, 1963
Ontario - cattle	ingesta containing ave 35.7 ppm As toxic (range 2.3 to 104 ppm)	Hatch and Funnell, 1969
Swine:		
Chester white pigs	22 ppm As as arsenic trioxide or 19 ppm As as Lead arsenate for 1 yr not toxic	Groves, McCulloch, and St. John, 1946
Sheep:		
Western feeder lambs	690 ppm As as arsenilic acid for 8 wk toxic	Bucy, Garrigus, Forbes, Norton, and Moore, 1955
Lambs	82.8 ppm As as arsenilic acid not toxic	Bucy, Garrigus, Forbes, Norton, and Moore, 1955

Table 7. Continued.

Test Animal	Daily Feed Intake (Dry Weight)	Author
Feeder lambs	on alfalfa pasture containing 62 ppm As for 36 hr in alfalfa toxic (wet weight)	Nelson, Crane, and Tomson, 1971
Horses:	1.3 to 1.9 grams As in diet daily not toxic (equal to 378 to 558 ppm As in forage of 500 lb horse)	Magill, Holden, Ackley, 1956

Table 8. Potentially toxic zinc levels for livestock.

Test Animal	Daily Feed Intake (Dry Weight)	Author
Cattle:		
Hereford calves (steers and heifers)	900 ppm Zn as ZnO for 12 wk toxic	Ott, Smith, Harrington, and Beeson, 1966b
Jersey and Holstein lactating dairy cows	1,279 ppm Zn and ZnO for 6 wk not toxic	Miller, Clifton, Fowler, and Perkins, 1965
Swine:		
Duroc weanling pigs	2000-4000 ppm Zn as ZnO for 10 wk not toxic	Cox and Hale, 1962
Various breeds of weanling pigs	1000 ppm Zn as ZnCo$_3$ for 6 wk maximum amount tolerated	Brink, Becker, Terrill, and Jensen, 1959
Sheep:		
Western lambs	1500 ppm Zn as ZnO for 10 wk toxic	Ott, Smith, Harrington, and Beeson, 1966a
Horses:		
Mares	570 ppm Zn for 57 wk not toxic - nursing foals normal	Graham, Sampson, and Hester, 1940
Pinto and standard-bred type fillies	90 mg Zn/kg body wt/day for 30 wk toxic (equal to 3600 ppm Zn in feed)	Willoughby, MacDonald, McSherry, and Brown, 1972a

Table 9. Potentially toxic cadmium levels for livestock.

Test Animal	Daily Feed Intake (Dry Weight)	Author
Cattle:		
Holstein and Jersey heifer calves	160 ppm Cd as $CdCl_2$ for 5 days toxic	Powell, Miller, and Clifton, 1964a
Holstein and Jersey bull calves	160 ppm Cd as $CdCl_2$ for 12 wk toxic	Powell, Miller, Morton and Clifton, 1964b
Non pregnant lactating Holstein cows	250-300 ppm Cd as $CdCl_2$ for 2 wk toxic (didn't establish lowest toxic level)	Miller, Lampp, Powell, Salotti, and Blackmon, 1967
Swine:		
Yorkshire barrows	50 ppm Cd as $CdCl_2$ for 6 wk decreased weight gains	Cousins, Barber, and Trout, 1973
Yorkshire pigs	154 ppm Cd as $CdCl_2$ for 8 wk decreased weight gains (Zn offset Cd toxicity)	Pond, Chapman, and Walker, 1966
Swine	150 ppm Cd as CdO not toxic; while 300 ppm Cd as CdO toxic	Clarke and Clarke, 1967
Sheep:	- - - - none recorded - - - -	- - - - - - - - - - - - - - - -
Horses:	- - - - none recorded - - - -	- - - - - - - - - - - - - - - -

Table 10. Potentially toxic lead levels for livestock.

Test Animal	Daily Feed Intake (Dry Weight)	Author
Cattle:	Forage contaminated with 25-46 ppm Pb toxic	Cited in Kradel, Adams, Guss, 1965
	6-7 mg Pb/kg body weight/day toxic (equal to 200-300 ppm Pb in forage)	Aronson, 1972; Hammond and Aronson, 1963
Swine:		
Hampshire pigs	66 mg Pb/kg body wt/day as lead acetate for 14 wk toxic	Link and Pensinger, 1966
Chester white pigs	10.4 ppm Pb as lead acetate or 79 ppm Pb as lead arsenate for 1 yr not toxic	Groves, McCullock, and St. John, 1946
Sheep:		
Lambs 2 to 10 wk old	herbage which contained 427 ppm Pb (ave) toxic	Abstract: Am. Vet. Med. Ass. J. 130:22
Ewes, cows, and calves	herbage which contained 427 ppm Pb (ave) not toxic	Abstract: Am. Vet. Med. Ass. J. 130:22
Lambs	261 to 914 ppm Pb in herbage toxic	Stewart and Allcroft, 1956

Table 10. Continued.

Test Animal	Daily Feed Intake (Dry Weight)	Author
Young lambs	162 to 764 ppm Pb in forage toxic (278 ppm ave)	Butler, Nisbet, and Robertson, 1957
Lambs	41.1 to 258 ppm Pb in forage toxic (158 ppm ave)	Innes and Shearer, 1940 (cited in Butler et al. 1957)
Lambs	37 to 215 ppm Pb in forage toxic (96.5 ppm ave)	Shearer, Innes, and Mc-Dougall, 1940 (cited in Butler, et al. 1957)
Lambs	6.0 to 91.1 ppm Pb in forage toxic (20.4 ppm ave)	Shearer and McDougall, 1944 (cited in Butler, et al. 1957)
Lambs	427 ppm Pb (ave) in forage toxic	Stewart and Allcroft, 1956
Ewes (pregnant)	50 ppm Pb as lead acetate equal to 1 mg Pb/kg body wt/day toxic	Allcroft and Blaxter, 1950
Ewes (not pregnant)	250 ppm Pb as lead acetate equal to 5 mg Pb/kg body wt/day can be tolerated for 1 yr	Allcroft and Blaxter, 1950
Ewes (not pregnant)	400 ppm Pb as lead acetate equal to 8 mg Pb/kg body wt/day for 220 days toxic	Allcroft and Blaxter, 1950

Table 10. Continued.

Test Animal	Daily Feed Intake (Dry Weight)	Author
Horses:		
Horses	1.7 mg Pb/kg/body wt/day toxic (about 80 ppm Pb in forage)	Aronson, 1972
Horses	2.4 mg Pb/kg/body wt/day toxic (about 113 ppm Pb in forage)	Hammond and Aronson, 1963
Pinto and standardbred type fillies	3400 ppm Pb in diet for 30 wk toxic - 86 mg Pb/kg body wt/day	Willoughby, MacDonald, McSherry and Brown, 1972a

selection has contributed significantly to the degree of damage around many smelters. Reports of smelters or other industrial facilities with amplified sulfur dioxide and/or heavy metal damage that were located in valleys are numerous (Jordan, 1975; Miller, et al., 1975; Treshow, 1970; Whitby and Hutchinson, 1974; and Gorham and Gordon, 1960a). As a contrast, reports of damage around smelters located in the Central Plains have been minimal, possibly as a result of excellent dispersion afforded by the relatively flat topography and persistent winds. The frequency of synoptic scale atmospheric stagnation (based on a study by Holzworth, 1972) has been utilized in ranking the major nonferrous smelters for potential meteorological associated damage (Table 11). Unlike a nocturnal inversion which is broken up by sunshine, a synoptic scale atmospheric stagnation may persist for days and increasingly fumigate a region. Topographic influences, especially non-level terrain, may create low level microcirculations; however, these will not alleviate the widespread stagnation which usually covers thousands of square miles. Also, tall stacks are of little benefit since the inversion remains aloft and acts as a thermodynamic lid on upwards mixing of effluents. Based on Holzworth's study (1972), the smelters most affected by meteorological conditions are located in Garfield, Utah; McGill, Nevada; and Copperhill, Tennessee, while those least affected are located in White Pine, Michigan; Bartlesville, Oklahoma; El Paso, Corpus Christi, and Amarillo, Texas; and Herculaneum, Missouri.

Table 11. Potential number of high stagnation days in a five-year period occurring in the vicinity of domestic primary nonferrous smelters.

Plant Name	Location	Stagnation Days (Number)*
Copper Smelters		
Anaconda	Anaconda, Montana	10
Asarco	Tacoma, Washington	20
Asarco	El Paso, Texas	5
Asarco	Hayden, Arizona	15
Cities Service	Copperhill, Tennessee	35
Inspiration	Miami, Arizona	17
Kenecott	McGill, Nevada	38
Kenecott	Garfield, Utah	45
Kenecott	Hayden, Arizona	15
Kenecott	Hurley, New Mexico	11
Magma	San Manuel, Arizona	17
Phelps Dodge	Ajo, Arizona	19
Phelps Dodge	Douglas, Arizona	10
Phelps Dodge	Moreni, Arizona	18
White Pine	White Pine, Michigan	0
Zinc Smelters		
Amax	Blackwell, Oklahoma	0
Asarco	Amarillo, Texas	0
Asarco	Corpus Christi, Texas	0
Asarco	Columbus, Ohio	20
Bunker Hill	Kellogg, Idaho	20
National Zinc	Bartlesville, Oklahoma	0
New Jersey Zinc	Palmerton, Pennsylvania	18
St. Joe	Monaca, Pennsylvania	20
Lead Smelters		
Asarco	El Paso, Texas	5
Asarco	Glover, Missouri	9
Asarco	E. Helena, Montana	9
Bunker Hill	Kellogg, Idaho	20
Missouri Lead	Boss, Missouri	4
St. Joe	Herculaneum, Missouri	5

*Number of days in a five-year period.

VII. Future Levels of Damage

In the past, copper smelters have emitted to the atmosphere approximately 14 percent of the total arsenic in the ore processed. From a process standpoint, these emissions are directly associated with those of sulfur oxides. Unfortunately, two-thirds of the arsenic emitted during copper smelting is volatilized during roasting and smelting operations, whereas two-thirds of the sulfur oxides released are emitted with the flue convertor gases. Furthermore, only one-third to one-half of the arsenic in the flue gases is captured by dust collection devices. The new standards requiring 90 percent sulfur oxide recovery have forced an increase in copper ore leaching. This process change not only will decrease sulfur loss but will also decrease arsenic and other heavy metal loss (EPA, 1975). At present, the copper smelting industry alone emits about 4800 metric tons of arsenic per year. This quantity alone is greater than all other airborne arsenic emissions combined. As newer smelters are built and made operational or as existing smelters are modified to meet the new standards, arsenic emissions from copper and other nonferrous smelters are expected to decrease, as is the acreage affected by airborne emissions. Furnace residues and slags are expected to contain slightly higher arsenic concentrations after implementation of these changes.

Possibly the most significant arsenic loss within the industry is associated with fugitive dust from land disposal of stack dusts, furnace residues and mine tailings (Table 6). With time, chemical and biological processes oxidize these wastes, and much of the arsenic in these wastes becomes bound as arsenates to iron and aluminum oxides. As mentioned previously, in severely denuded watersheds (Coeur d'Alene) or basins (Copperhill) a substantial amount of these wastes may be leached through the soil column or carried as runoff with subsequent release of arsenic and/or other heavy metals into natural waters. Since the U. S. Environmental Protection Agency and various state agencies have limited arsenic discharge from point sources via wastewaters, nonferrous smelters presently release only minor amounts of arsenic and other heavy metals in their wastewaters (EPA, 1975a, b, c, and d). The contribution of leaching and runoff of arsenic from land destined wastes may be locally significant (Smalley, 1975); however, in general, arsenic in natural waters is of limited potential toxicity. The reasons for this limited toxicity are:

(1) arsenic is either bound in sediments or insolubilized in soil;

(2) arsenic becomes from 10 to 60 times less toxic when it is oxidized from the trivalent to pentavalent form; and

(3) municipal water treatment plants effectively reduce arsenic to acceptable limits.

More stringent disposal restrictions and stabilization programs, if instituted for land disposed wastes, would not only reduce the mobilization of arsenic and other heavy metals into the neighboring environs, but also would provide a recoverable resource to future generations.

If present levels of emissions are maintained, the level of ecological damage could possibly increase. Ores being smelted in the future may contain higher concentrations of arsenic and other impurities as the United States relies more on foreign ores. In addition, the percentage of the desired metals in ores will continue to decrease as the richer ores are expended. Consequently, more and more ore will need to be processed in order to provide the same quantity of metals. The ability of the environs of a given smelter to continue to accept this loading will depend on a number of variables, such as:

(1) soil type;
(2) soil depth;
(3) soil texture;
(4) percent organic matter;
(5) amount of iron and aluminum oxides in soil;
(6) soil pH;
(7) vegetative type;
(8) climate; and
(9) topography.

However, as the quality and quantity of ores decrease, newer, more efficient metal extraction processes will need to be developed and utilized, as will newer particulate control strategies. Secondary smelters will also become more important as recycling becomes an economic necessity of our society. In general, with the need to recover a greater percent of a diminishing resource, the loss of arsenic and other heavy metals during smelting and mining is expected to decrease even further. The secondary copper industry presently supplies about 30 percent of the United States copper demand.

In conclusion, the limited literature and the resource inventories of each of the major smelters suggest that most of the acreage around U.S. nonferrous smelters provides only slightly elevated levels of arsenic to the local biota, and the role of arsenic as a toxicant appears of minor consequence compared to that of lead, cadmium, zinc, copper, and oxides of sulfur. If a study of arsenic and its effects on food resources around smelters is deemed necessary, a reconnaissance survey of locally produced crops, forage, aquatic resources, and livestock products is advised. The contribution of fugitive dust and the importance of sediments and residues to arsenic cycling and loading are poorly defined and warrant the development of ecological protocols.

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APPENDIX A

Resource Inventories

Anaconda Copper Smelter, Anaconda, Montana

Located in the vicinity of U.S. 10A in southwestern Montana, Anaconda is surrounded by natural forest lands (Deer Lodge, Bitteroot, and Beaverhead National Forest). Most lands within five miles of the smelter belong to Anaconda. The smelter is the only significant source of industrial emissions in the area. Land use is as follows:

1 mile radius: 100% industrial/settling ponds/tailing piles

5 mile radius: 75% range
10% urban/industrial/settling ponds and tailing piles
5% improved pasture

10 mile radius: 40% range
40% timber
15% improved pasture
5% urban/industrial

AGRICULTURAL RESOURCES

Potatoes are cultivated in insignificant amounts, while alfalfa is grown on improved pastures. Little cultivation occurs within five miles of smelter, as most SO_2 damage is contained within this area (Roginske, 1975). Extensive barren areas still exist from the 1940-1950's (thistles are spaced 10 feet apart).

RANGE/PASTURE RESOURCES

Production of beef cattle occurs on most rangeland and pasture, with a limited number of horses being raised. Stocking rates on range vary from three acres/animal/month on good range to 20 acres/animal/month on poor range. After harvest of alfalfa from improved pastures, stocking rate is approximately two acres/AUM*. Principal pasture forage species are alfalfa, orchardgrass, and smooth brome (*Bromus enervus*). Principal range forage species are bluebunch wheatgrass (*Agropyon spicatum*), Idaho fescue (*Festuca idahoensis*) and rough fescue (*Festuca scabrella*). No adverse effects upon livestock have been noted due to smelter emissions (Roginske, 1975). Swain and Harkins (1908) linked emissions of 30 ton/day arsenic oxide from the Anaconda smelter (Montana) with the death of cattle, sheep, and horses grazing in the vicinity of this smelter. Emissions were reduced with the installation of electrostatic dust collectors and Cottrell bag precipitators, and the problem was corrected.

FORESTRY RESOURCES

Most commercial timber occurs at elevations of 5000-7000 feet, with lodgepole pine and Douglas fir being the most important species. Rotation age is 100-120 years.

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* AUM = Animal Unit Months

AQUATIC/FISHERY RESOURCES

The major aquatic resource within 10 miles of the smelter is Clark's Fork of the Columbia River, located approximately six miles northeast of the smelter. Warm Spring Creek is located two miles north of the smelter. Silver Lake, Georgetown Lake, and other smaller mountain lakes occur in the 10 mile radius. Smelter tailing ponds reportedly have effluent into Clark's Fork. No commercial fishing occurs in the area, though recreational trout fishing does occur in Clark's Fork.

GEOHYDROLOGY

The Deer Lodge Valley runs in a generally north/south direction and is approximately 10 miles long and two miles wide. Elevation is 5300 feet, with mountains around the valley being 8000-10,600 feet high. The smelter itself is located on a hill just at the mouth of a canyon at an elevation of 4800 feet. Potable water is obtained from Silver and Georgetown Lakes and Warm Spring Creek. The water table is "very high."

CLIMATE

Average annual rainfall is 12 inches; winds prevail from the southwest, although they are variable due to topographic modifications. Inversions occur occasionally.

Asarco Copper Smelter, Ruston (Tacoma), Washington

GENERAL INFORMATION

The smelter is located in the Ruston suburb of Tacoma (Pierce County) in western Washington. It borders Puget Sound, with larger portions of the Sound occurring to the northeast, north, and southwest. Land use is primarily residential, both on the islands within the Sound and on the mainland to the south and east. Two major industries occurring 10 to 12 miles southeast of the smelter are Kaiser Aluminum and a pulp mill.

AGRICULTURAL RESOURCES

A study conducted for the U.S. EPA by Ratsch (1974) on the effects of Cu, Zn, Cd, Pb, As, Hg, and SO_2 emissions from the copper smelter in Ruston, Washington, identified levels of As in soils and vegetation toxic to sensitive and moderately sensitive plant species (snap beans, lima beans, onion, peas, cucumber, alfalfa, and other sensitive legumes). The absence of legumes in the vicinity of the smelter was hypothesized to be associated with the high Cu and As levels in the soil. In addition, within the study area damage to peach trees was linked with SO_2 and As emissions from the smelter. During 1970, the Ruston smelter emitted about 550 tons per day SO_2, 0.4 tons per day As, and 0.3 tons per day Pb. Generally, the levels of As in vegetation and soil decreased as distance from the smelter increased (Figures 1a and 1b). Crecelius, Johnson, and Hofer (1974 reported elevated levels of As in soil up to six miles from the smelter.

FORESTRY RESOURCES

There are limited numbers of commercial Douglas fir within 10 miles of smelter.

AQUATIC/FISHERY RESOURCES

Puget Sound and associated waters provide a wealth of sport fishing. Although oyster harvesting does occur in the bay, there are no suitable oyster beds within 10 miles of the smelter. The smelter is not known to release effluent into the Sound.

GEOHYDROLOGY

The smelter is located right on the Sound (sea level), and the topography of the general area is that of steep 100 foot hills.

CLIMATE

Summer winds are from the north-northwest; fall, winter, and early spring winds are from the south and southwest. Precipitation averages 38 inches annually.

Fig. 1a

Arsenic concentration (ppm) in vegetation in the Tacoma area (AFTER RATSCH, 1974).

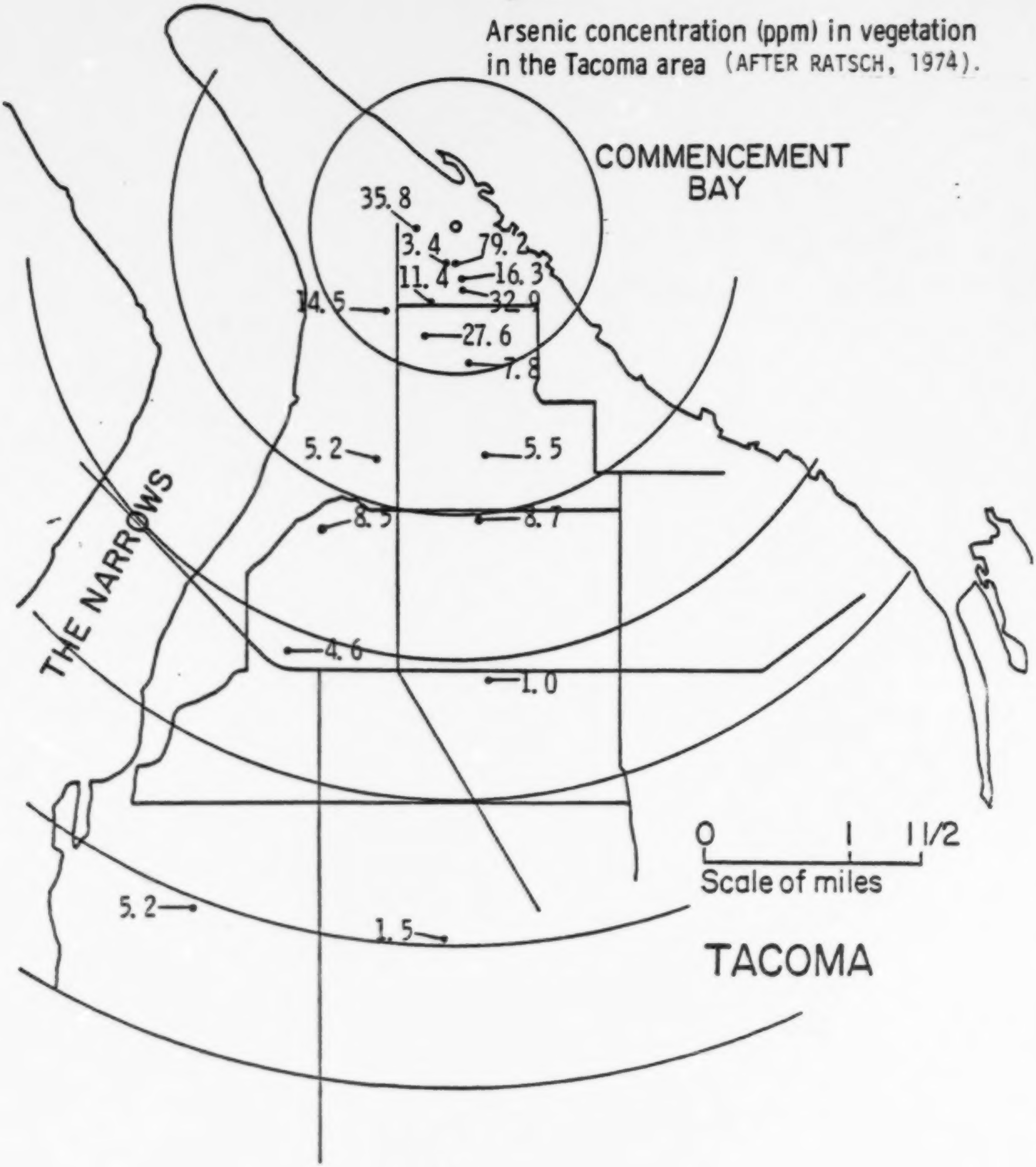
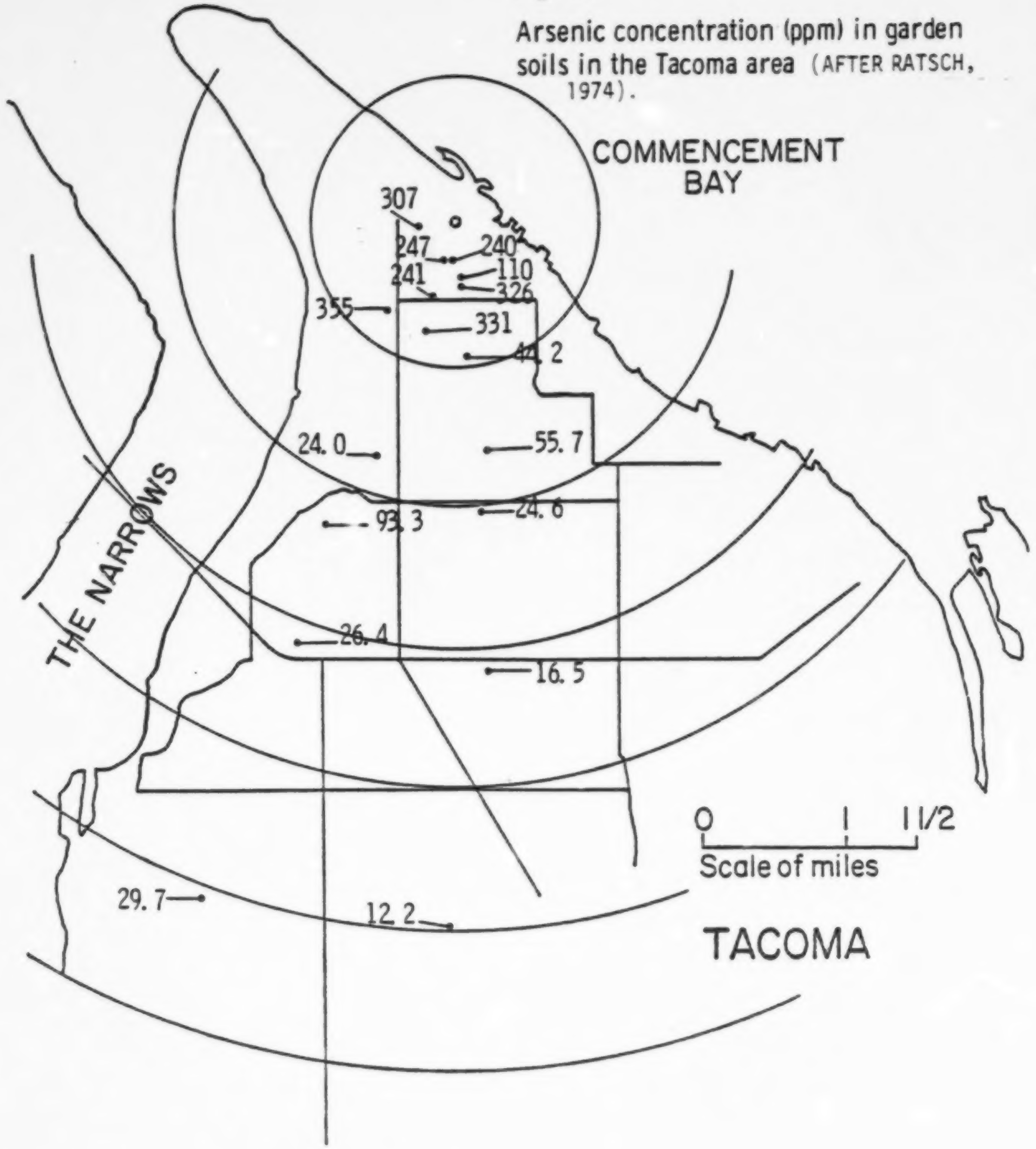

COMMENCEMENT BAY
35.8
3.4
79.2
11.4
16.3
14.5
32.9
27.6
7.8
5.2
5.5
THE NARROWS
8.5
8.7
4.6
1.0
0
1
11/2
Scale of miles
5.2
1.5
TACOMA

Fig. 1b

Arsenic concentration (ppm) in garden soils in the Tacoma area (AFTER RATSCH, 1974).


COMMENCEMENT
BAY
307
247
240
241
110
326
355
331
44.2
24.0
55.7
THE NARROWS
93.3
24.6
26.4
16.5
0
1
1 1/2
Scale of miles
29.7
12.2
TACOMA

Asarco Copper/Lead Smelters, El Paso, Texas

GENERAL INFORMATION

Located in the most westerly portion of Texas and on the Mexican border, El Paso is located in a narrow river valley surrounded by mountains. The major highway in the vicinity of the smelter complex is Interstate 10. The two smelters are evidently combined in the same complex, as there are no other Asarco smelters in the region; though there is one Phelps Dodge smelter. Land use in the vicinity of the smelter is as follows:

1 mile radius:	80% urban/industrial 20% undeveloped (mountainsides)
5 mile radius:	70% urban/industrial 30% undeveloped
10 mile radius:	60% urban/industrial 30% undeveloped 10% agriculture

It is important to note that the Texas Air Quality Board brought suit against Asarco a few years back, and the smelter has subsequently cleaned up its operation.

AGRICULTURAL RESOURCES

Major crops in the river valley are cotton and alfalfa, with minor amounts of grain sorghum and vegetables also being produced. No damage to crops or natural vegetation has been noted due to the smelter. Croplands are irrigated from river water with some farms having reservoirs to catch and hold water from floods of the Rio Grande River.

RANGE/PASTURE RESOURCES

The El Paso region is one of deserts and steep slopes, consequently there is little grazing of livestock.

AQUATIC/FISHERY RESOURCES

The Rio Grande River is a shallow, narrow river (70-80 feet wide) that flows intermittently in its northern portions. Its intermittent nature is due largely to upstream dams which hold water through the fall or early winter, releasing it in January or February. No significant fishery resource exists in the El Paso area.

GEOHYDROLOGY

El Paso is located in a very narrow river valley at an elevation of approximately 3600 feet. The smelter complex is located adjacent to the river, and yet elevations within one mile east or west of the smelter are 6000 feet or more. The Franklin Mountains rise 7000 feet to the east. Wells provide potable water for the region, the water table being between 200-500 feet deep.

CLIMATE

Precipitation averages seven inches per year, occurring mostly in July through September. Prevailing winds are from the southwest, and are especially strong from February to May (30-40 mph is common, gusts to 80 mph).

OTHER INFORMATION

El Paso extends across the Mexican border and has a total population of approximately one million. With the exception of a Phelps Dodge smelter and two petrochemical refineries located eight miles east-southeast of the Asarco complex, it is primarily an area of light industries.

Cities Service Copper Smelter, Copperhill, Tennessee

GENERAL INFORMATION

Located in the southeastern corner of Tennessee (Polk County) on State Road 68, Copperhill is surrounded by national forest lands (Cherokee, Chattahoochee, and Nantahala National Forests). The smelter is the only significant source of emissions in the area; however, significant ecological damage has been associated with the smelting, timbering, and stumping practices of the mid nineteenth century. Land use in the smelter vicinity is as follows:

1 mile radius: 25% residential
75% barren ground or industrial

5 mile radius: 20% pasture
40% forest
5% residential
35% barren

10 mile radius: 20% pasture
40% forest
1% residential
39% barren

AGRICULTURAL RESOURCES

Agriculture in the vicinity of the smelter consists only of small home gardens.

RANGE/PASTURE RESOURCES

Pastures are located mostly to the south and east of the smelter, which is generally the area of least SO_2 damage from smelter emissions. Feeder calf production occurs at a stocking rate of one cow per one to one and one-half acres, with little woodland grazing occurring. Pasture forage species are primarily orchardgrass and fescues, with bluegrass being important in some areas. Direct adverse effects upon livestock have not been observed (Switzer, 1975).

FORESTRY RESOURCES

The national forest lands in the vicinity of the smelter are commercially operated for both pines and hardwoods, each comprising about 50 percent of the timber production. Important pines are white pine, Virginia pine, and loblolly pine. Upland oak, northern red oak, and yellow poplar are important hardwoods.

There are approximately 30,000 acres in the smelter vicinity which contain less than 50 percent vegetation, with highly damaged areas occurring north and west of the smelter. Lesser damage has occurred in most of the remaining forestland in the area. Most damage has resulted from past SO_2 emissions, timbering, and stumping.

AQUATIC/FISHERY RESOURCES

Aquatic resources in the area are: 1) Ocoee River, located approximately 200 yards from the smelter; 2) a small stream very close to the smelter; 3) Campbell Cove Lake, five miles north-northwest of the smelter; 4) Ocoee #3, a 300 acre dammed reservoir three miles downstream from the smelter; 5) Ocoee #2, a four acre impoundment 10 miles downstream from the smelter; and 6) Lake Ocoee, a 1900 acre reservoir 20 miles downstream from the smelter.

Cities Service is currently constructing a settling treatment plant for process effluents. Process effluents are presently being dumped into the Ocoee River, and judging from observations, effluent may be composed largely of the iron component of the ore. This, combined with erosion from devegetated lands, has led to sedimentation (acidity problems in the entire Ocoee River System). Ocoee #3 is highly sedimented and has a projected useful life of 33 years. Ocoee #2 also has a sedimentation problem. Lake Ocoee has 100 to 150 years projected useful life (as compared to 1500 to 2000 years for similar reservoirs elsewhere). Campbell Lake to the north-northwest (upstream) is the only water body unaffected by the smelter operation. Fish are nonexistent in all affected water bodies except Lake Ocoee, and fish there are maintained only with stocking--reproduction is very poor. Paucity of fish may be related to water acidity, sedimentation and turbidity, or heavy metals. Cities Service is neutralizing acidity of effluent and/or receiving water bodies by the addition of lime. In 1973, water sampled one mile downstream from the smelter had less than 5 mg/l total As, while sediments contained 23 mg As/Kg (dry weight). The Public Health Drinking Water Standard for As is 0.01 mg/l.

GEOHYDROLOGY

The copper operation is located in a basin of low, rolling, broken hills. The basin is surrounded by mountains on three sides, having a somewhat open plateau to the south. The smelter occupies 12 to 15 acres on the west edge of Copperhill. Source of potable water for the whole Ocoee Utility District is the Ocoee River system; the district intake is located two miles below Lake Ocoee.

CLIMATE

The Copperhill region is subject to 55 inches of rain annually and generally southwesterly winds modified by local topography. Downslope winds often occur in winter from the east. The driest portion of the year is September to November, with inversions also occurring frequently in the fall.

Inspiration Copper Smelter, Miami, Arizona

GENERAL INFORMATION

The Inspiration copper smelter is located in a generally mountainous region of south-central Arizona (Gila County) on U.S. 60 not far from State Road 88. The smelter is the only significant source of emissions in the area. Land use in the vicinity of the smelter is as follows:

1 mile radius: 100% urban/industrial (owned by smelter)

5 mile radius: 75% urban/industrial
25% Tonto National Forest land (20% range, 5% timberland)

10 mile radius: 50% urban/industrial
50% Tonto National Forest land (35-40% range, 10-15% timberland)

Much of the land north of the smelter is in Tonto National Forest.

AGRICULTURAL RESOURCES

There is no significant agricultural land use within 10 miles of the smelter; although there are a few backyard gardens.

RANGE/PASTURE RESOURCES

A small amount of winter pasture (60 acres) is within the 10 mile zone, growing barley, rye grass, and bermudagrass. However, most beef cattle production occurs on open range at a stocking rate of seven to nine cows/section. Important forage species are sideoats grama (*Bouteloua curtipendula*), hairy grama (*Bouteloua hirsuta*), curly mesquite (*Hilaria belangeri*), false mesquite (*Calliandra eriophylla*), desert ceanothus (*Ceanothus graggii*) and hollyleaf buckthorn (*Rhamnus crocea*).

Leaf burns have been noticed irregularly on mulberry and sycamore trees in the vicinity of the smelter. Damage has not been noted to evergreens. Annuals have been extirpated from the vicinity of the smelter, although the causitive factor(s) are unknown. Laurel (*Rhus ovata*) is also a sensitive specie which has exhibited damage possibly from SO_2. False mesquite (*Calliendra eriophylla*) is evidently resistant and thrives in the vicinity of the smelter. A golf course located three miles from the smelter shows irregular damage to cottonwoods. A few tailing areas are located on national forest rangelands. No adverse effects have been noted on livestock (Wilson, 1975).

FORESTRY RESOURCES

Ponderosa pine (Pinus ponderosa) occupies most of the forestlands, with smaller amounts of pinyon pine (Pinus edulis) being harvested.

AQUATIC/FISHERY RESOURCES

With the exception of a few small ponds, there are no permanent water bodies within 10 miles of the smelter.

GEOHYDROLOGY

Elevation of the smelter is approximately 3500 feet, the smelter being located on a ridge. Elevation varies within the 10 mile radius by 750 feet, reaching a peak of 7200 feet at a radius of 15 miles. Mountain ranges are located north, south, and west of Miami; Miami being located on foothills carved with steep canyons. The source of potable water for the area is groundwater, with wells reaching depths of 600-700 feet.

CLIMATE

Annual rainfall averages 15-18 inches, with half falling in July-September and half falling during the winter. Prevailing winds are from the southwest at 5-10 mph. Inversions are infrequent.

Kennecott Copper Smelter, McGill, Nevada

GENERAL INFORMATION

McGill is located in eastern central Nevada (White Pine County) on U.S. 93. The region is mountainous, with the Kennecott smelter being the only significant source of industrial emissions in the area. Land use in the vicinity of the smelter is as follows:

1 mile radius:	50% urban/industrial
	50% mountain
5 mile radius:	50% mountain range (public lands)
	25% agriculture
	20% non-mountain range (public lands)
	5% urban/industrial/residential
10 mile radius:	75% mountain range
	15% agriculture
	10% urban/industrial/residential

AGRICULTURAL RESOURCES

Irrigated crops consist almost entirely of forage crops, with alfalfa hay being the most important. Small grains such as barley, wheat, and oats are also grown in the area. Agricultural land presently occurs in close proximity (two to three miles) to the McGill area.

RANGE/PASTURE RESOURCES

No pasture resources presently exist in the area; however, both mountain and valley ranges are used in beef cattle production. Lands are controlled by the Bureau of Land Management. Principal forage species are crested wheatgrass (*Agropyron cristatum*), Indian ricegrass (*Oryzopsis hymenoides*), and bluebunch grass (*Agropyron spicatum*). Although no damage has been noted upon crops, natural vegetation, or livestock due to heavy metals, some SO_2 damage to vegetation has been noted in the vicinity of the smelter (Mateson, 1975).

AQUATIC/FISHERY RESOURCES

Bassett Lake (300 acres) is located three to four miles west of the smelter and is composed of tailwaters from the smelter. Fish include trout, northern pike, and bass. There is also limited use of the lake by waterfowl. Duck Creek and an impoundment which occur seven to eight miles northeast of the smelter contain mostly trout.

GEOHYDROLOGY

The smelter is located on high, dry soils on the "toe" of a mountain. Elevation is approximately 6200 feet, rising to 8000-10,000 feet within one mile east of the smelter. The smelter was also described as resting on a level cone which sloped gradually (50 feet/mile) to the north and west. The valley to the west has a level topography.

Kennecott has a water storage reservoir on Duck Creek, seven to eight miles northeast of the smelter. This reservoir provides potable water for McGill.

CLIMATE

Precipitation occurs throughout the year, averaging about eight to nine inches annually. Winds are usually from the southwest, being strongest in the spring. Inversions are infrequent. Observations indicate that the plume from the smelter usually rises well, with no residences occurring downwind (northeast) of the stack.

Kennecott Copper Smelter, Garfield, Utah

GENERAL INFORMATION

Bounded by the Oquirrh Mountains to the south and Great Salt Lake to the north, Garfield is a very small town 20 miles west of Salt Lake City. Interstate 80 is the nearest major highway to the smelter, and no other significant sources of industrial emissions occur in the area. Land use in the vicinity of the smelter is as follows:

1 mile radius:	85%	range
	10%	industrial
	5%	wetland
5 mile radius:	55%	range
	25%	water
	15%	tailings area
	3%	residential
	2%	industrial
10 mile radius:	35%	range
	30%	water
	15%	cropland
	5%	salt flats
	5%	tailings areas
	8%	residential
	2%	industrial

AGRICULTURAL RESOURCES

Little cultivation occurs in the Garfield area except for pasture/hay/feed species such as alfalfa, grains, and corn silage. Small amounts of SO_2 damage have been noted in the vicinity of the smelter; alfalfa leaf burns by SO_2 have occurred nine miles southwest of the smelter at Erda (Hardin, 1975; Braithwaite, 1975).

RANGE/PASTURE RESOURCES

Beef cattle production occurs on both native range and irrigated pasture. Stocking rates on pasture vary from 0.5 AUM/acres for poorly managed pastures to 8 AUM/acre for well managed pastures. Stocking rates on range are roughly three to four acres/AUM. Most seeded pasture is tall fescue. Native pastures include wiregrass (*Cynoden dactylon*), blue sedge, redtop (*Agrostis idahoensis*), Kentucky bluegrass (*Poa pratensis*), saltgrass (*Distichum spicata*), and white dutch clover (*Trifolium* sp.). Important range species are bluebunch wheatgrass (*Agropyron spicatum*), little junegrass (*Koeleria cristata*), squirreltail (*Sitanion* sp.), and Nevada bluegrass (*Poa nevadensis*). At present there are no adverse effects upon livestock due to the smelter. However, there were problems with livestock near the smelter 20 years ago (Hardin, 1975; Braithwaite, 1975).

AQUATIC/FISHERY RESOURCE

The smelter lies one mile south of Great Salt Lake. Brine shrimp and brine shrimp eggs are the only commercial fishery products of the lake.

GEOHYDROLOGY

The elevation of Great Salt Lake is 4200 feet. The smelter is at 4250 feet, and is within a couple of miles of both the lake and the Oquirrh Mountains to the south. The mountains are reached within one-half mile of the smelter and, within five miles, 10,000 feet peaks are encountered. The smelter is located in the foothills, with its stacks being located well up the mountain side. The smelter reportedly reaches three to four to four miles in an east-west direction. Potable water is obtained from springs to the west (near Lake Point Junction), from Deer Creek reservoir, and from irrigation wells. The groundwater table is 70 to 150 feet below ground surface.

CLIMATE

Precipitation averages 12 to 13 inches annually; prevailing winds are from the northwest in the winter and the southwest in the summer. Inversions occasionally occur in the fall and winter.

OTHER INFORMATION

Approximately 10 to fifteen years ago, smelters were operable in Bauer and east of Tooele -- these may have caused some vegetation damage.

Kennecott/Ascaro Copper Smelters, Hayden, Arizona

GENERAL INFORMATION

Hayden is located in southeastern Arizona (Pinal County) near the intersection of State Highways 76, 77, and 177. The two smelters occur in close proximity to each other. Land use in the smelter area is as follows:

1 mile radius:	20% agricultural 50% residential 30% range
5 mile radius:	20% residential 80% range
10 mile radius:	10% residential 90% range

Important emission sources other than these two smelters do not occur in the Hayden area.

AGRICULTURAL RESOURCES

A small amount of agricultural land occurs along the Gila River. Major crops are cotton, alfalfa, wheat, barley, and milo. No damage to crops or natural vegetation has been noted in relation to smelter emissions (Hale, 1975).

RANGE/PASTURE RESOURCES

Beef cattle are raised on open range at a stocking rate of about one cow/640 acres. Pleasure and work horses may also be found in the area. Important forage species are Lehmann lovegrass (*Eragrostis lehmannii*), sideoats grama (*Bouteloua curtipendula*), various annuals, and buckbrush. The range may be generally described as the desert shrub type.

AQUATIC/FISHERY RESOURCES

The Gila River (perennial) and San Pedro River (intermittent) converge approximately one mile southwest of the smelters. Some minor catfish fishing may occur in the Gila River.

GEOHYDROLOGY

The smelters are located at the foot of a mountainous area, and are specifically located in the bottom of an abrupt canyon which is less than one mile wide. Elevations range from 2500 to 3000 feet. Potable water is obtained from wells at depths of about 1200 feet.

CLIMATE

Summer rains account for most of the annual precipitation of 12 inches. Prevailing winds average 15 mph, and are out of the southwest. Small thermal inversions occur in the wintertime, usually breaking up by midday. Plumes from smelter stacks disperse well when there are winds, and tend to drop back into the canyon when the air is still.

Kennecott Copper Smelter, Hurley, New Mexico

GENERAL INFORMATION

Hurley is located in southwestern New Mexico (Grant County) on U.S. 180. Land use in the vicinity of the Kennecott smelter is as follows:

1 mile radius:	50% range 50% urban industrial (encompasses most of town)
5 mile radius:	95% range 4% urban/industrial 1% agriculture
10 mile radius:	99% range 1% urban/industrial

AGRICULTURAL RESOURCES

An insignificant amount of acreage is used to produce alfalfa.

RANGE/PASTURE RESOURCES

Range production of beef cattle is the dominant land use in the area. Stocking rate is one AU (year)/50 acres; and cattle presently use rangeland in the vicinity (one mile) of the smelter. Blue grama (*Bouteloua gracilis*) and sideoats grama (*Bouteloua curtipendula*) are the dominant forage species. No damage to crops, range vegetation, or livestock has been noted due to smelter emissions (Bray, 1975). However, there are ambiguous reports of damage to range vegetation due to smelter effluents (not from holding ponds as mines are not located in the Hurley area). The exact nature of smelter effluents is not known.

AQUATIC/FISHERY RESOURCES

There are no permanent water bodies within 10 miles of the smelter.

GEOHYDROLOGY

Elevation of the smelter is 5500 feet; the elevation in the 10 mile radius varying by a maximum of 1000 feet. Topography is quite variable, being fairly level at the smelter and to the south, rolling hills to the west, and steep slopes to the north. Potable water is from wells.

CLIMATE

Precipitation averages 16 inches annually, falling mostly from July to October. Prevailing winds are from the southwest.

OTHER INFORMATION

Other appreciable emission sources in the area other than the Kennecott smelter do not exist.

Magma Copper Smelter, San Manuel, Arizona

GENERAL INFORMATION

Located in southeastern Pinal County, Arizona, on State Road 77, the Magma Copper Smelter at San Manuel occurs just north of one of the many tracts of the Coronado National Forest. No other significant industrial emissions occur in the smelter vicinity. Land use is as follows:

1 mile radius: 80% urban/industrial
20% range

5 mile radius: 3% urban/industrial
10% agriculture (pasture)
87% range

10 mile radius: 5% urban/industrial
10% agriculture (pasture)
85% range

Magma's mine is within the 10 mile region.

AGRICULTURAL RESOURCES

The limited crops in the vicinity of the smelter are forage crops, consisting mostly of alfalfa and small grains.

RANGE/PASTURE RESOURCES

Beef cattle production occurs at a stocking rate of 7-40 head/acre on irrigated pasture and 120-150 acres/cow year on open range. Principal forage species are: sideoats grama (Bouteloua curtipendula), canebeard grass (Andropogon sp.), bush muhly (Muhlenbergia porteri), Arizona cottontop (Trichachne californii) and rothrock grama (Bouteloua rothrockii). Livestock damage due to heavy metals occurred three years ago when livestock utilized water and pasture irrigated by water which had been run through tailing areas (Lamoreaux, 1975). Water levels were low at that time, so contaminants were undoubtedly concentrated as evapotranspiration occurred. Tailing water was not from the Magma operation, but from a smaller operation which has since closed.

AQUATIC/FISHERY RESOURCES

The San Pedro River runs directly east (within one-half mile) of the smelter and is intermittent--being dry for approximately six months out of the year. There are a few small springs in the area which dry out within a few miles of their sources.

GEOHYDROLOGY

The area is one of rolling grasslands with steep breaks (canyons 5-100 feet deep) which lead into the San Pedro River. Elevation of San Manuel is 3200 feet; this rises to 5000 feet by Orache to the west, rising again to the east after the river is crossed. A very gradual decrease occurs in overall elevation as one moves south. Potable water is obtained from wells at depths of less than 100 feet.

CLIMATE

Precipitation is 10 inches annually, occurring from November to September. Winds are from the southwest, and are typically strong or nonexistent. Observations indicate that inversions are infrequent and that the smelter plume usually rises well.

Phelps Dodge Copper Smelter, Ajo, Arizona

GENERAL INFORMATION

Ajo is located in southwest Arizona (Pima County), and is traversed by State Highway 85. The Phelps Dodge smelter and mine comprises the only industry in the area. Lands to the north and west of the town are part of an Air Force gunnery range; whereas lands to the south are controlled by the Bureau of Land Management. Land use within a one, five and 10 mile radius of the smelter is as follows:

1 mile radius:	20% open pit mine
	25% rock refuse
	25% dust/sand tailings
	30% residential
5 mile radius:	25% residential
	75% open range
10 mile radius:	15% residential
	85% open range

AGRICULTURAL RESOURCES

There are no agricultural lands within a 10 mile radius of the smelter site. No damage has been noticed on natural vegetation due to the SO_2 or heavy metals (Voget, 1975).

RANGE/PASTURE RESOURCES

No irrigated pastures occur within the 10 mile radius, however, natural rangeland is the dominant land type surrounding Ajo. Rangelands to the north are not utilized, since this area is used as a gunnery range. Beef cattle are the only non-wild stock on the range, and they occur primarily to the south on lands controlled by the Bureau of Land Management. Stocking levels are low, with much of this area being in the Lower Sonoran Life Zone. Forage grasses are generally uncommon, with Tobosa grass (*Hilaria mutica*) and Galleta (*Hilaria jamesii*) being the only significant species. No adverse effects upon livestock have been observed due to smelter emissions (Voget, 1975). Production of mesquite honey occurs to the south and west of Ajo. Hives are not located to the north or east because the honey tends to pick up a sulfur flavor.

WILDLIFE RESOURCES

Important game species in decreasing order of importance (as rated according to annual man-hours spent hunting) are mourning dove, Gambel's quail, and mule deer.

AQUATIC/FISHERY RESOURCES

There are no aquatic/fishery resources in the Ajo area.

GEOHYDROLOGY

The elevation of Ajo is 1775 feet, and within a 10 mile radius elevations vary from 900 to 2500 feet. Both extremes in elevation are located west/northwest of the smelter, where sharp desert mountains rise steeply out of the surrounding flatlands. Creosote flats occur to the northeast, east and south of the smelter at elevations of 1400 to 1800 feet. Potable water for Ajo is obtained from deep wells sunk by Phelps Dodge approximately eight miles north of the town. Depth to the water table is 250 to 500 feet.

CLIMATE

Precipitation at Ajo averages nine inches per year. This figure remains the same 10 miles east of the town, but decreases to three inches per year 10 miles west. Rain occurs in the form of thunderstorms from July to September. Prevailing winds are from the south/southwest, occasionally coming from the southeast or west.

Phelps Dodge Copper Smelter, Douglas, Arizona

GENERAL INFORMATION

Douglas is situated on the U.S./Mexican border in southern Cochise County, southeast Arizona. The area described does not include lands south of the border. Major highways servicing Douglas are U.S. 80 and U.S. 666. Land use within a one, five, and 10 mile radius of the smelter is as follows:

1 mile radius: 15% vacant unused rangeland
85% varied uses in connection with the smelter. (Phelps Dodge controls most of the land within one mile of the smelter)

5 mile radius: 15% cropland
30% urban/residential
55% open range

10 mile radius: 5-10% cropland
10% urban/residential
80-85% open range

AGRICULTURAL RESOURCES

A limited amount of agriculture occurs in the region five to 10 miles from the smelter, mostly in the form of small farms. Farms in the Double Adobe area (northwest of Douglas) produce alfalfa, winter wheat, and chile peppers. Farms in the Cochise College area produce winter wheat and grain sorghum. A large ranch (the Rainbow Inn Ranch) is found about six miles west of the smelter. Major crops produced by the ranch are corn silage, winter and spring wheat, grain sorghum, and alfalfa.

No damage to crops has been noted in the last one and one-half years. However, farmers have been paid for damages in the past (though it is not known whether this damage was to crops or stock).

RANGE/PASTURE RESOURCES

Production of beef cattle on open range is the dominant land use within a 10 mile radius of the smelter. One small goat ranch (30-50 goats) is located approximately 10 miles from the smelter. Principal forage species on open range are Tobosa grass (*Hilaria mutica*) and Galleta (*Hilaria jamesii*). Tobosa grass dominates on rangelands north of Douglas, forming colonies to the exclusion of other species. Lands to the west support mesquite and plains bristlegrass. Stocking levels on open range vary from four to 15 AUM/section (year round). The Rainbow Inn Ranch has improved, irrigated pastures which are planted to tall fescue (Festuca sp.). Stocking levels for improved pasture are 18 AUM/acre. Damage has not been noted to livestock or range due to the smelter or other sources (Rosenau, 1975). However, livestock damage has occurred farther north in the San Pedro Valley due to stock drinking water containing the effluent from smelter/mine operations.

AQUATIC/FISHERY RESOURCES

Whitewater Draw passes through the Douglas area, but the draw flows only after periods of rainfall. A few farm ponds with fish, frogs, etc. are scattered throughout the 10 mile region. The nearest major water body is Rucker Lake, located 40 miles north/northeast of the smelter.

GEOHYDROLOGY

The elevation of Douglas is 4000 feet above MSL. The town is located on gently sloping alluvial fill which drops 20 to 30 feet per mile in a southerly direction. Local topographic variations of 20 to 30 feet are due primarily to entrenched streams. The Perilla Mountains rise to 5500 feet east of Douglas, and these are the only mountains occurring within 10 miles of the smelter. Ranges are also located at distances of 20-25 miles both north and west of Douglas. Potable water is obtained from wells; the water table occurring 90 to 100 feet below the surface.

CLIMATE

Annual precipitation averages 12.5 inches, with approximately 10 inches falling from July to September. Winds are usually from the south or west, with spring being the windiest period. Wind speed averages 10 knots. The average temperature is 62°F, with a range of 10° to 100° occurring in the course of a year.

OTHER INFORMATION

Except for the smelter, Douglas supports only light industries with insignificant emissions. A lime plant is located 10 miles west of the smelter at Paul Spur, and this produces substantial amounts of particulates. Dirt roads are the next most important source of particulates in the area.

Phelps Dodge Copper Smelter, Morenci, Arizona

GENERAL INFORMATION

Morenci is located in Greenlee County of southeastern Arizona. The major highway servicing Morenci is U.S. 666. Land use in the vicinity of the smelter is as follows:

3 mile radius: 85% smelter and open pit mine
15% company town

5 mile radius: 40% smelter and mine
15% urban/residential
45% open range

10 mile radius: 10% smelter and mine
10% urban/residential
80% range

AGRICULTURAL RESOURCES

Significant agricultural land use does not occur within 10 miles of the smelter. Small amounts of alfalfa and truck crops are produced 15 miles southeast of the smelter. No damage to crops or natural vegetation due to the smelter has been noted in recent years (McKosky, 1975).

RANGE/PASTURE RESOURCES

Beef cattle production is the major land use in the Morenci area. Horses are also raised in the area. At present no improved pasture occurs within this 10 mile radius. Important range forage species are blue grama (*Bouteloua gracilis*) and sideoats grama (*Bouteloua curtipendula*). Stocking rates are 1.5 cows/section annually, and this rate is affected partially by the steepness of the terrain. No adverse effects upon livestock due to the smelter have been noted (McKosky, 1975). Sources other than the smelter/mine operation do not exist in the Morenci area.

AQUATIC/FISHERY RESOURCE

The San Francisco River is a permanent flowing stream of variable size, and it flows approximately 2.5 miles due east of the smelter. Primary use is recreational, with limited catfish/carp fishing occurring. No effluent is released into the river from smelter/mine operations.

GEOHYDROLOGY

The elevation of Morenci is approximately 3500 feet, and the region is topographically characterized as one of rolling hills with deep sharp canyons. There are mountains to the north/northeast, and within the 10 mile radius elevations approach 7000 feet. The smelter is located on a ridge top. Potable water is obtained from the river, with only about 5 percent of the population using well water (mostly in subdivisions). Depth of the water table increases as one goes farther from the river, and is 600 feet deep approximately five miles from the river.

CLIMATE

Precipitation averages 12 to 14 inches annually; occurring mostly between July and August. Prevailing winds are from the southwest. Inversions occur primarily from mid-November to mid-December (occasionally occurring mid-December to March), and usually break by midday.

OTHER INFORMATION

The regional U.S.F.S. office has conducted studies on SO_2 effects on vegetation surrounding the Morenci smelter. No damage was noted.

White Pine Copper Smelter, White Pine, Michigan

GENERAL INFORMATION

White Pine is located approximately six miles south of Lake Superior in northwestern Michigan (Ontonagon County). The town is located on State Road 64, and there are no significant sources of industrial emissions within 10 miles of the smelter. A pulp mill is located 15 miles northeast of the smelter in Ontonagon. Land use in the vicinity of the smelter is as follows:

1 mile radius:	20% residential
	40% tailing ponds
	40% woodland
5 mile radius:	1% residential
	4% tailing ponds and industrial
	95% woodland
10 mile radius:	1% residential, industrial, etc.
	99% woodland

AGRICULTURAL RESOURCE

Farming is insignificant in the area, with a few small farms occurring within the 10 mile radius to the east. Vegetables and potatoes may be grown on portions of the farms.

RANGE/PASTURE RESOURCE

There is an insignificant number of cattle on farms and horses pastured in the White Pine vicinity. No adverse effects have been observed on livestock or vegetation due to smelter emissions (Fisher, 1975).

WILDLIFE RESOURCES

A large (1000 to 1500 acres) tailing pond area exists one-half mile east of the smelter. This area has become established as a goose landing/resting station. The degree of goose feeding activity while on the tailing ponds is not known.

FORESTRY RESOURCE

Commercial timber species are sugar maple and aspen--with the area also supporting yellow birch, basswood, cottonwood, hemlock and spruce. The northern boundary of the Ottawa National Forest lies 1.5 miles south of White Pine.

AQUATIC/FISHERY RESOURCES

The Iron River lies one mile west of the smelter and Lake Superior lies six miles to the north. Recreational fishing for lake and river trout, and coho salmon occurs throughout the area. It is not known whether effluents occur from the smelter or tailing ponds into these water bodies.

GEOHYDROLOGY

White Pine occurs in flat lands at an elevation of roughly 850 feet. Porcupine Mountains State Park lies two miles west of the smelter with peaks of 2000 feet, and is the only area with significantly variable topography. Flat lands continue east, north, and south of the smelter, a gradual downslope occurring towards Lake Superior (600 feet). The area has clay soils, and river and streams consequently carry relatively high sediment loads with corresponding high turbidity.

CLIMATE

Precipitation averages 33 inches annually. Prevailing winds are from the southwest in summer and from the northwest in the winter. Inversions rarely occur.

Asarco Zinc Smelter, Amarillo, Texas

GENERAL INFORMATION

In May of 1975 the Asarco zinc smelter located due north of Amarillo was closed. A new smelter is being erected northeast of Amarillo on State Road 136, and is tentatively scheduled to begin operations in 1976. The distance between the two smelters is 15 miles.

Amarillo is located in the central portion of the Texas panhandle. Both smelters are in Potter County. Land use in the vicinity of the two smelters is as follows:

Old Smelter:

1 mile radius: 75% residential
25% range

5 mile radius: 50% residential
50% range

10 mile radius: 50% residential
50% range

New Smelter:

1 mile radius: 95% range
5% commercial (mostly right-of-ways)

5 mile radius: 95% range
5% commercial (mostly right-of-ways)

10 mile radius: 75% range
10% cropland
15% commercial

AGRICULTURAL RESOURCES

No agricultural land use occurs within 10 miles of the old smelter. Small amounts of wheat and grain sorghum are produced 5 to 10 miles from the new smelter. No damage to crops or natural vegetation has been noted due to the old smelter (Brooks, 1975).

RANGE/PASTURE RESOURCE

Beef cattle production on open range is the major land use in the Amarillo region. Minor production of horses also occurs. One hog farm is located approximately 10 miles from the old site. Principal forage species on open range are: buffalo grass (Buchloe dactyloides), blue grama (Bouteloua gracilis), and sideoats grama (Bouteloua curtipendula). Stocking rates on open range are approximately 1 AUM/25 to 30 acres. No adverse effects upon livestock have been noted due to smelter emissions (Brooks, 1975).

AQUATIC/FISHERY RESOURCES

No aquatic/fishery resources exist in the Amarillo area, which has only small creeks. The nearest major water body is Lake Meredith 75 miles to the north.

GEOHYDROLOGY

Amarillo, at an elevation of 3600 feet, is in an area of rolling 30 to 40 foot hills. The potable water source for 70% of Amarillo is Lake Meredith, with approximately 30% of the water being drawn from wells. The water table is located at a depth of about 250 feet.

CLIMATE

Approximately 18 to 20 inches of precipitation occurs annually in Amarillo, falling mostly from May to July. Prevailing winds are from the southwest.

Asarco Zinc Smelter, Corpus Christi, Texas

GENERAL INFORMATION

The Asarco zinc smelter is located a few miles south of Nueces Bay in the vicinity of Corpus Christi, San Patricio County, Texas. Interstate 37 is the major highway transversing the smelter vicinity. Land use in the vicinity of the smelter is as follows:

1 mile radius:	75% urban/residential
	25% agriculture
5 mile radius:	50% urban/residential
	10% agriculture
	40% water
10 mile radius:	60% urban residential
	15% agriculture
	25% water

Agricultural areas tend to be located north and west of the smelter; whereas urban/industrial areas are located to the south and east. A complex of petrochemical refineries is located two miles southwest of the smelter.

AGRICULTURAL RESOURCES

Grain sorghum is the most important crop in the vicinity of Corpus Christi. Cotton is also produced, though not in the abundance of former years. No damage has been noted to crops of natural vegetation due to the smelter emissions (Frankenhauser, 1975).

RANGE/PASTURE RESOURCES

Significant amounts of range or pasture do not occur within 10 miles of the smelter.

AQUATIC/FISHERY RESOURCES

Major water bodies in close proximity to the smelter are Nueces River, Nueces Bay, and Corpus Christi Bay. The smelter is located on a ship-turning basin south of Nueces Bay and roughly east-southeast of where the Nueces River empties into the bay. Both bays are important in the production of sport fish and shrimp. Oysters are unimportant (except in terms of dredging oyster shell).

GEOHYDROLOGY

The source of potable water for Corpus Christi is the Nueces River. A limited number of wells occur, the water table (for potable water) being from 120 to 200 feet deep. Elevation at the smelter site is roughly 25 feet. Generally speaking, the topography gradually slopes towards the north (further south it slopes towards the southeast), decreasing at a rate of about six feet/mile.

CLIMATE

Twenty-seven inches of precipitation occur in average years, with the most rainfall occurring in August and September, and smaller amounts falling in March and April. Prevailing winds are from the southeast, with an average speed of about 18 mph. Inversions rarely occur.

Asarco Zinc Smelter, Columbus, Ohio

GENERAL INFORMATION

The Asarco smelter is on the southeastern edge of Columbus, close to the town of Obetz. The only other significant source of industrial emissions in the area is the Brown Steel plant, eight miles north-northwest of the smelter. Land use in the vicinity of the smelter is as follows:

1 mile radius: 65% urban/industrial/residential
35% agriculture

5 mile radius: 60% urban/industrial/residential
40% agriculture

10 mile radius: 50% agriculture
45% urban/industrial/residential
5% woodland

AGRICULTURAL RESOURCES

Most of the "agriculture" category is improved pasture. Moderate amounts of corn and small amounts of soybean, wheat, and vegetables are grown within the ten mile radius. A 300 acre vegetable farm lies six miles north of the smelter. No damage to crops or natural vegetation has been noted (McNutt, 1975).

RANGE/PASTURE RESOURCES

One dairy farm is located within ten miles, to the south of the smelter. Stocking rate averages three cows per acre of pasture, and little other cattle production occurs in the area. A number of farms with horses occur, mostly south of the smelter. Two or three horses per five acre lot is usual. Pasture forage species are bluegrass, alfalfa, clover, and brome grass. Such pastures are often planted semi-annually to corn, being plowed up and returned to pasture after production of corn is completed. The smelter has not been observed to have had adverse effects upon livestock (McNutt, 1975).

AQUATIC/FISHERY RESOURCES

Scioto River occurs five miles west of the smelter, Alum Creek occurs three miles east, and Big Walnut Creek occurs four miles south. No commercial fishing occurs in these waterways, only recreational fishing. The smelter is not known to have effluent into any of these water bodies.

GEOHYDROLOGY

The smelter occurs in a fairly flat area at an elevation of 850 feet (elevation change in a ten mile radius is less than 100 feet). The source of potable water is probably from Alum Creek, Scioto River, and various other runs.

CLIMATE

Precipitation averages 38 inches annually; winds are variable but mostly from the northwest. Inversions are infrequent.

Bunker Hill Zinc and Lead Smelter, Kellogg, Idaho

GENERAL INFORMATION

Located in the vicinity of Interstate 90 in northern Idaho (Shoshone County), the combined zinc and lead smelter is located just south of Kellogg. It is the only significant source of industrial emissions in the area. Land use in the vicinity of the smelter is as follows:

1 mile radius:	100% industrial
5 mile radius:	75% forest/brushland 25% urban/industrial/residential
10 mile radius	90% forest/brushland 10% urban/industrial/residential

AGRICULTURAL RESOURCES

No significant agriculture occurs within 10 miles of the smelter. Although portions of the valley were at one time cultivated, effluent and tailings have accumulated in the river valley and cultivation is no longer feasible. Lack of cultivation may be partly attributable to heavy metals in effluent/tailings.

RANGE/PASTURE RESOURCES

No significant range/pasture resource is located within 10 miles of the smelter.

FORESTRY RESOURCES

Slopes close to Smelterville and Kellogg have been denuded by SO_2 and fire, and revegetation occurs very slowly due to SO_2-related acid soil conditions. On slopes south of Kellogg, 90% denudation has occurred within one mile of the smelter. By five miles the vegetation approaches normal conditions. North facing slopes generally support grand fir and red cedar. South facing slopes support Douglas fir, grand fir, and some ponderosa pine.

AQUATIC/FISHERY RESOURCES

The south fork of the Coeur D'Alene River runs one and one-quarter miles north of the smelter. The north fork is within the 10 mile radius both to the west and north. Fishery resources in these rivers are primarily recreational. A 160 acre tailing pond is located west of Kellogg, with another tailing pond being located west of Smelterville.

GEOHYDROLOGY

General topography of the area is a narrow river valley (one-half mile wide) sided by steep 4000 to 6000 foot peaks. The smelter itself is on a small tributary ("draw") of the Coeur D' Alene River. The draw is oriented north-northeast/south-southwest and is 200 to 300 yards wide. The elevation is 2600 feet, with 3700 feet being reached in one mile and 6000 foot peaks in a few miles. Potable water is probably obtained from the river. Water table varies, bedrock usually being within five feet of the surface.

CLIMATE

Rainfall averages 25 to 30 inches in the valley and 30 to 40 inches in the mountains. Winds are variable and inversions occur fairly often.

National Zinc, Zn Smelter, Bartlesville, Oklahoma

GENERAL INFORMATION

Bartlesville is located in northeastern Oklahoma (Washington County) on U.S. 75. The National Zinc smelter is the only significant source of industrial emissions in the area. Land use in the vicinity of the smelter is as follows:

1 mile radius:	75% industrial/residential 25% agricultural (of which 10% is pasture and 15% rangeland)
5 mile radius:	30% residential 15% industrial 55% agricultural (range)
10 mile radius:	15% residential 5% industrial 80% agricultural (range)

Residential/industrial areas are generally located south, east, northeast, and northwest of the smelter. Agricultural (range) areas are located to the southwest.

AGRICULTURAL RESOURCES

There is very little cropland in the smelter vicinity.

RANGE/PASTURE RESOURCES

Rangeland comprises most of the area in the vicinity of the smelter. A small portion of this is improved pasture, with tall fescue (Festuca arundinacea) and bermudagrass (Cynodon dactylon) being the important forage species. Important forage species on native range are little bluestem (Andropogen scoparius), big bluestem (Andropogen gerardi), Indiangrass (Sorghastrum nutans), and switchgrass (Panicum virgatum). Production of beef cattle occurs on improved pasture at a stocking rate of one cow per two to five acres. Stocking rates on native range average one cow per 12 acres. Smelter emissions have not been observed to have had adverse effects upon livestock or vegetation in the Bartlesville area (Hunter, 1975).

AQUATIC/FISHERY RESOURCES

The Caney River, which is perennial and small, flows through Bartlesville. No effluent from the smelter is known to enter the river. Forty-acre Lake Bardue four miles north-northwest of the smelter, is situated with Hudson Lake seven miles to the north-northwest. No significant fishery resources exist in the Bartlesville area.

GEOHYDROLOGY

Elevation of the smelter is approximately 700 feet. Topography at the smelter site is fairly level, with flatlands continuing to 10 miles east of the smelter. Two miles west of the smelter rough, rolling hills are encountered with elevation differences of approximately 100 feet. Bartlesville city water is obtained from Lake Bardue and Hudson Lake.

CLIMATE

Winds prevail from the southwest at an average of 15 mph. Annual precipitation averages 30 inches. Inversions sometimes occur.

Amax Zinc Smelter, Sauget, Illinois

GENERAL INFORMATION

Sauget is located just south of East St. Louis on State Road 3, in western St. Clair County, Illinois. The Mississippi River flows approximately 3/4 miles west of Sauget, with U.S. 40 crossing State Road 3 1-1/2 miles north of Sauget. Significant industrial plants within 1 mile of the Amax smelter are: Edwin-Cooper plant (oil additives), Monsanto Chemical Plant (this is the largest, producing about 20 chemicals), Cerro Copper Company, Midwest Rubber Recycling Company, and the Union Electric Company generating station (300 megawatts--not in continuous operation). Most of these are located in an industrialized area within diked portions of the river's former floodplain. Land use within 1, 5, and 10 mile radius of the smelter is as follows:

1 mile radius:	70% industrial 30% residential	(excluding Mississippi River)
5 mile radius:	10% industrial 70% residential 20% agricultural	
10 mile radius:	10% industrial 60% residential 30% agricultural	

AGRICULTURAL RESOURCES

Most farming occurs on bottomlands safeguarded by flood protection levees. Major crops are: sweet corn, wheat, soybeans, and some truck crops. No damage to crops has been noted, though vegetation will not grow in some portions of the industrial area due to SO_2 or other emissions (Schluger, 1976).

GEOHYDROLOGY

The smelter is located on former bottomlands now protected by levees approximately 1/2 mile east of the levee. Elevation of the site is approximately 400 feet, being flat in the river bottomlands. The floodplain is approximately 10 miles wide, being sided by steep bluffs (within 5 miles to the east of the smelter) rising to 600 feet. Water is obtained from the East St. Louis municipal water supply.

CLIMATE

Most of the annual precipitation of 30-40 inches occurs in spring and early summer. Prevailing winds are from the southwest in the summer and northwest in the winter. Inversions do occur.

OTHER INFORMATION

A cadmium processing/recovery unit is being added to the Amax smelter. Small amounts of arsenic and zinc may leak from the smelter or escape to the air. Arsenic is used as an additive to purify the zinc liquours; however, traps are maintained to collect potential leakages.

New Jersey Zinc, Zinc Smelter, Palmerton, Pennsylvania

GENERAL INFORMATION

Located in Carbon County of eastern Pennsylvania, Palmerton is situated in a narrow river (Lehigh River) valley. State Road 248 is the major highway servicing the area. Aside from the two New Jersey zinc smelters in the area, there are no other significant industrial emission sources within 15 miles (Jordan, 1975). Only one smelter is a primary smelter. Land use in the vicinity of the primary smelter is as follows:

1 mile radius:	50%	woodland
	20%	residential
	15%	industrial
	10%	open pit mines
	3%	water
	2%	streets and highways
5 mile radius:	60%	woodland
	15%	field crops
	5%	pasture
	7%	industrial/mines
	13%	residential
10 mile radius:	60%	woodland
	20%	field crops
	5%	pasture
	5%	industrial/mines
	10%	residential

AGRICULTURAL RESOURCES

Corn and small grains are the principal field crops. Many areas formerly cultivated are now barren due to SO_2/heavy metal damage.

RANGE/PASTURE RESOURCES

Bluegrass, tall fescue, and orchardgrass are principal pasture forage species. Cattle are stocked at a rate of one cow/three to five acres. Very little woodland grazing occurs, and smelter emissions have not been observed to have had any direct effect upon livestock (Emerheiser, 1975).

FORESTRY RESOURCES

No commercial forestry occurs in the area, primarily because of stress conditions and steep slopes. The slopes of Blue Mountain to the south (see Geohydrology) are sparsely vegetated or barren over an area of 485 ha. (1200 acres). Vegetation surviving (mostly sassafras) is depauperate, chlorotic, necrotic, and exhibits leaf curling. Species exclusion has occurred for many species. Damage is due primarily to high Zn and Cd levels in the soil with SO_2 damage and Cu and Pb levels playing a lesser role (Jordan, 1975).

AQUATIC/FISHERY RESOURCES

The smelter is located on the Lehigh River, and is one-fourth to one-half mile northwest of where Aquashicola Creek enters the river. No natural reproduction occurs in the river, though trout have been stocked. The smelter does not discharge into the creek, though there is a possibility of effluent into the river. The river has sedimentation/turbidity problems with coal silts.

GEOHYDROLOGY

Palmerton is located in a narrow valley bounded on the south by Blue Mountain and on the north by Stony Ridge. The valley is oriented northeast-east/southwest-west. Town elevation is 500 feet; ridge elevation is 1500 feet. Soils are sandy and well drained (with much rock), with potable water for the area being obtained from artesian wells.

CLIMATE

Precipitation averages 41 inches annually. Winds are primarily from the northwest, but are variable due to topographic features. The average annual temperature is 10° C.

St. Joe Lead Company Zinc Smelter, Monaca, Pennsylvania

GENERAL INFORMATION

Monaca is in Beaver County in western Pennsylvania. It is located at the intersection of State Roads 68 and 18, and lies just south of the Ohio River. Other industries are common in the area: Arco Palmers Copper plant is one-half mile south of the smelter, J & L Steel is four to five miles south, and the John Mansfield Power plant is located four miles west of the smelter. Land use in the vicinity of the smelter is as follows:

1 mile radius:	10% agriculture
	50% woodland
	40% urban/industrial
5 mile radius:	15% agriculture
	30% woodland
	55% urban/industrial
10 mile radius:	20% agriculture
	55% woodland
	25% urban/industrial

AGRICULTURAL RESOURCES

Corn is the crop most commonly grown on agricultural lands, with small amounts of pasture occurring five to ten miles from the smelter. St. Joe owns agricultural lands within one mile of the smelter (corn is usually grown). Some SO_2 damage has occurred in the area (Curran, 1975; Council, 1975).

RANGE/PASTURE RESOURCES

No native range occurs in the area, though limited amounts of woodland grazing do occur. There is a very limited number of cattle on the area's pastures. Stocking rate in this area of the state is about one to two head/acre per year. The small number of cattle may be partially due to decreased productivity of forage species dues to smelter emissions. Bluegrass (*Poa* sp.) is the principal forage species. The smelter has not been observed to have direct adverse effects upon livestock (Curran, 1975).

FORESTRY RESOURCES

No commercial harvesting of timber occurs in the area. St. Joe smelter has a planting of Scotch and Austrian pine close to the smelter; growth is suppressed.

AQUATIC/FISHERY RESOURCES

Ohio River is the major water body in the smelter vicinity--water quality of the river is generally poor. Beaver River flows into the Ohio River from the north with somewhat cleaner water. Insignificant amounts of carp and catfish are caught in these rivers.

GEOHYDROLOGY

The smelter is located on the Ohio River bank at an elevation of approximately 600 feet. Steep hills are encountered as one moves away from the river, elevations rising to 1200 feet. Potable water is obtained from wells at variable depths (30 to 100 feet).

CLIMATE

Annual precipitation averages 44 inches. Winds prevail from the west, and inversions occur infrequently. Plumes from the smelter have been observed as usually rising well.

Amax Zinc Smelter, Blackwell, Oklahoma

GENERAL INFORMATION

Blackwell is located in north central Oklahoma (the western half of Kay County). The smelter lies two miles east of Interstate 35. No other significant sources of industrial emissions occur in the vicinity of the smelter. Land use in the area is as follows:

1 mile radius:	8%	cropland
	35%	residential/urban
	47%	company owned land
	10%	pasture
5 mile radius:	84%	cropland
	12%	residential/urban
	4%	pasture
10 mile radius:	93%	cropland
	5%	residential/urban
	2%	pasture

Amax has recently closed this smelter.

AGRICULTURAL RESOURCES

Winter wheat is the principal crop on agricultural lands in the Blackwell area, accounting for approximately 90% of the land in production. Alfalfa, corn, sorghum, and small grains account for the remaining areas. Small amounts of SO_2 damage have been noted, and the Zn and Pb content of some fields of wheat, sorghum, and field corn were found to be high enough to be potentially toxic to livestock. Alfalfa and hairy vetch were found to contain metal levels safe for livestock.

RANGE/PASTURE RESOURCES

The principal pasture species is Bermudagrass, and Zn, Pb, Cd, and As levels in forage immediately north of the smelter were high enough to be potentially hazardous to livestock. Cattle grazing too close to the smelter in the past have been subject to weight loss. There is a record of one horse death four miles north of the smelter due to Pb/Zn poisoning. Zn and Cd were also related to decreased productivity of pastures close to the smelter (Benenati, 1974).

AQUATIC/FISHERY RESOURCES

Chickaskia River is located one mile northeast of the smelter, and Stink Creek occurs one and one-half miles to the west. Analysis of river water samples revealed acceptable levels of Zn, Cd, Pb, and As. However, some creeks, farm ponds, drainage ditches, and other areas concentrating local runoff had Zn, Cd, or Pb levels which exceeded Federal water quality criteria.

GEOHYDROLOGY

The region is one of level to gently undulating plains crossed by occasional creeks and rivers. Potable water for the region is obtained from wells, and acceptable levels of Zn, Pb, Cd, and As were found in all groundwater samples (Benenati, 1974).

CLIMATE

Precipitation averages 28.6 inches annually. Winds prevail from the south, often coming from the north in winter. Average wind speed is 15 mph. Average temperature is 16°C.

Anaconda Zinc Smelter, Black Eagle, Montana

GENERAL INFORMATION

Located in Cascade County of west-central Montana, Black Eagle is immediately east of Great Falls on U.S. 87. Closed in August of 1972, the smelter was the only major source of industrial emissions in the area. Land use in the vicinity of the smelter is as follows:

1 mile radius:	80% agriculture
	10% sanitary landfill
	10% residential
5 mile radius:	80% agriculture
	20% residential
10 mile radius:	90% agriculture or rangeland
	10% residential

AGRICULTURAL RESOURCES

Agricultural areas lie north of the smelter, producing mostly winter wheat. No damage has been noted to crops or natural vegetation due to smelter emissions (Wirak, 1975).

RANGE/PASTURE RESOURCES

A limited amount of range exists with livestock being 30% beef cattle and 70% pleasure horses. The principal range forage species is bluebunch wheatgrass. No adverse effects on livestock have been noted in the vicinity of the smelter (Wirak, 1975).

AQUATIC/FISHERY RESOURCES

The Missouri River is located adjacent to the smelter while the Sun River is within 5 miles of the smelter. Benton Lake National Wildlife Refuge occurs 8-10 miles to the north. There is presently a lagoon next to the smelter.

GEOHYDROLOGY

Steep river bluffs are encountered within 1/3-3/4 mile of the smelter. The region is generally one of sharp hills which are 150-250 feet high. Base evaluation is 3310 feet. Potable water for the area is taken from Benton Lake and Muddy Creek. The water table varies, sometimes being only 2-3 feet from the surface.

CLIMATE

Fourteen inches of precipitation occurs yearly, mostly in May and June. Winds prevail from the southwest; inversions occur occasionally.

Eagle-Picher Zinc Smelter (Roasting Plant), Galena, Kansas

GENERAL INFORMATION

Galena is located in the extreme southeastern corner of Kansas on U.S. 66, in Cherokee County. The smelter was closed in 1971, and was close to two ammonium nitrate fertilizer plants: one 3 miles NW, the other 1-1/2 miles due east (in Missouri). Land use in the vicinity of the smelter is as follows:

1 mile radius:	75% urban/industrial 10% improved pasture 15% wooded range
5 mile radius:	10% urban/industrial 10% cropland 30% improved pasture 50% wooded range
10 mile radius:	20% urban/industrial 15% cropland 25% improved pasture 40% wooded range

AGRICULTURAL RESOURCES

Major crops grown in the area are wheat and other small grains, with some production of soybeans and sorghum also occurring. No damange to crops has been noted due to the smelter (Worthy, 1976)

RANGE/PASTURE RESOURCES

The stocking rate on fescue improved pastures is 1 cow/7-8 acres, while Post oak-Blackjack Oak woodland is stocked at 1 cow/15 acres. Wooded range is fairly open, with about 50% canopy closure. Little Bluestem is the principal range grass with some switchgrass also occurring. An area of wooded range about 1 mile long, northeast of the smelter, has been denuded due to smelter emissions (Worthy, 1976).

AQUATIC/FISHERY RESOURCES

A small creek close to the smelter flows into the Spring River 3 miles to the west.

GEOHYDROLOGY

The area is one of steep, rolling 80 foot hills, closely associated with the Ozarks, and having rocky, cherthy soils. The smelter is located in a narrow valley 600-600 feet wide running ENE-WSW. Base elevation is 905 feet. The area is a transition zone between the Ozarks and plains, with hills blending into flatlands west of the Spring River. Potable water is obtained from wells 900-1300 feet deep.

CLIMATE

Average annual precipitation of 42" occurs monthly, April - June. Inversions seldom occurs; winds prevail from the southwest.

OTHER INFORMATION

Studies have been conducted by the Agricultural Research Service of the USDA on heavy metals in soil, crops, natural vegetation, cattle, milk, human blood and hair in connection with a litigation against the smelter for livestock damage (Brower, 1976; Lagerwerff and Brower, 1974; and Lagerwerff, Brower and Biersdorf, 1973).

In grass samples collected approximately 3-1/2 miles northeast of the smelter, Lagerwerff, Brower and Biersdorf (1973) found cadmium, copper, lead, and zinc concentrations as high as 55, 53, 244, and 3700 ppm respectively. Such levels of lead and zinc have been shown to be toxic to cattle (Kradel, Adams, and Guss, 1965; Hammond and Aronson, 1963; Aronson, 1972; Ott et al., 1966b). In addition, samples of grain sorghum collected in the smelter area were also found in some cases to have zinc concentrations exceeding potentially toxic levels for cattle. These samples were all collected in 1971.

Eagle-Picher Industries Zinc Smelter, Henryetta, Oklahoma

GENERAL INFORMATION

The Eagle-Picher smelter is located in east-central Oklahoma in Okmulgee County. Henryetta occurs near the intersection of I-40 and U.S. 75. The smelter, which was closed down in 1969, was of the horizontal retort type and was located in the northwestern corner of town. Land use in the vicinity of the smelter is as follows:

1 mile radius:	75%	urban/industrial
	12%	improved pasture
	13%	native grass pasture
5 mile radius:	5%	urban/industrial
	45%	scrubby timberland (transition between forest and prairie)
	25%	improved pasture
	25%	native grass pasture
10 mile radius:	2%	urban/industrial
	50%	scrubby timberland
	24%	improved pasture
	24%	native grass pasture

AGRICULTURAL RESOURCES

At present there are no crops grown commercially in the area.

RANGE/PASTURE RESOURCES

Beef cattle production occurs on pastures and scrubby timberland. Improved bermuda grass/fescue pastures support 6 AUM/year. Native grass pastures, composed primarily of big and little bluestem, switchgrass, and indiangrass, support 1.2 AUM/year. Damage to pastures has occurred due to the smelter, the land being denuded to 3/8 mile north of the smelter site. Clovers also would not grow north of the smelter, and it was found that young colts would not survive 3-5 miles downwind of the smelter (Worthy, 1976).

AQUATIC RESOURCES

The Deep Fork River is approximately 5 miles northeast of the smelter and also ten miles to the north. Ten miles to the east is Lake Eufaula (a large man-made reservoir). Coal Creek is located 3/4 mile north of the smelter. There still exist old slag piles several feet deep over which surface runoff flows before entering the creek.

GEOHYDROLOGY

Due to previous coal mines/oil operations in the area, most groundwater sources have been contaminated by saltwater and other contaminants. Subsequently, these waters have been condemned. It is unknown as to how much contamination occurs due to direct percolation through smelter slag piles. Potable water is obtained from small municipal lakes 8-10 miles southeast of Henryetta. Base elevation is approximately 700 feet, with steep rolling hills 100 feet high. The smelter is on the front side (bottom) of a hill with 18 percent slope directly south of Coal Creek Bottom.

CLIMATE

Percipitation averages 38 inches annually; winds are from the south-southwest; inversions are infrequent.

Matthiessen & Hegler Zinc Co., Meadowbrook, W. Virginia

GENERAL INFORMATION

Located north of Clarksburg (U.S. 19) in Harrison County, north-central West Virginia, the M&H smelter was closed in 1971. No other major industrial sources of emission occur in this area. Land use in the vicinity of the smelter is as follows:

1 mile radius:	35% previously denuded land now growing back
	35% fallow cropland
	30% residential
5 mile radius:	2% previously denuded land
	49% fallow cropland
	49% residential
10 mile radius:	20% agriculture
	40% fallow land
	40% residential/industrial

AGRICULTURAL RESOURCES

No major agriculture occurs close to the smelter.

RANGE/PASTURE RESOURCES

Thirty to forty years ago, sulfur dioxide emissions killed most vegetation within 1/2-3/4 mile downwind of the smelter (Bennett, 1976). Revegetation is now occurring, mostly with Rubus ("ripshins"), sassafras, deertongue (a grass), some broom sedge, and poverty grass.

AQUATIC/FISHERY RESOURCES

Creeks in the area are generally lifeless due to low acidity, related to deep coal mines. Contamination occurs near the headwaters much before they reach the smelter area. The smelter is located on a secondary terrace just above the West Fork River, and a pile of coal ash and smelter refuse is currently eroding into the river.

GEOHYDROLOGY

Potable water is obtained from wells. The entire area has been soil mapped, with the 1000 acre denuded area near the smelter being mapped separately. Soil pH is 5.6, which is relatively acid for this area. The soil in this denuded area also has a greater tendency to erode. River elevation is roughly 1000 feet, with elevations rising in the area to 1400 feet.

CLIMATE

Precipitation averages 44 inches annually. Winds prevail from southwest and inversions are rare.

American Zinc Co. Zinc Smelter, Dumas, Texas

GENERAL INFORMATION

The Dumas Smelter was closed in 1971 and was located 6 miles northeast of Dumas, Texas, on County Road 110 in Moore County at the intersection of U.S. 87 and U.S. 287. Ohter industrial emission sources in the smelter area are: an ammonia nitrate plant 3 miles east of the smelter, a small potash plant 2-3 miles from the smelter, and several small gas plants throughout the area. Land use in the vicinity of the smelter is as follows:

1 mile radius: 50% irrigated cropland
35% range
7% dry cropland
5% pasture
3% industrial

5 mile radius: 65% irrigated cropland
25% range
5% dry cropland
3% improved pasture
2% industrial/other

10 mile radius: 70% irrigated cropland
20% range
5% dry cropland
2% improved pasture
3% industrial/other

AGRICULTURAL RESOURCES

Crops on irrigated land are grain sorghum, corn, and wheat--with wheat being the principal crop on dry croplands. No damage has been noted to crops or natural vegetation in the smelter area (Rogers, 1976). Row type surface irrigation is used due to the flat topography.

RANGE/PASTURE RESOURCES

Improved pasture irrigated for beef production is planted to Kentucky fescue, and fall and western wheatgrass. Pasture stocking rates are 1 AU year/3-5 acres, while range stocking rates are 1 AU year/20-25 acres. Native forage species include blue and sideouts grama, western wheatgrass, and buffalograss. No smelter related adverse effects have been noted on livestock (Rogers, 1976).

AQUATIC/FISHERY RESOURCES

Lake Meredith is located 20 miles to the southeast. Palo Duro Creek is intermittent and relatively close to the smelter.

GEOHYDROLOGY

Potable water is obtained from wells 250-450 feet deep. The topography is extremely flat and level.

CLIMATE

Precipitation is 18-22 inches/year; winds prevail from southwest; frequent inversions occur.

New Jersey Zinc Smelter, Depue, Illinois

GENERAL INFORMATION

Depue is located in Bureau County in north-central Illinois, just south of I-80 and just east of I-180. Located on the north side of the Illinois River, there are no other major industrial emission sources in the vicinity of the Depue smelter. The smelter was closed in 1971. Land use in the vicinity of the smelter is as follows:

1 mile radius:	60%	urban/industrial
	25%	agriculture
	14%	wildlife/recreation area (state owned)
	1%	river
5 mile radius:	85%	agriculture
	15%	urban/industrial/other
10 mile radius:	90%	agriculture
	10%	urban/industrial/other

AGRICULTURAL RESOURCES

Major crops are corn and soybeans. Although no damage to row crops has occurred, trees within 1/2 mile northeast of the smelter have been killed or stunted (Pretzsch, 1976). This area is vegetated now by native prairiegrasses (indiangrass, some switchgrass and big bluestem).

AQUATIC/FISHERY RESOURCES

The smelter is located 1/4-1/2 mile from the Illinois River on a secondary terrace.

GEOHYDROLOGY

Steep river bluffs occur between terraces adjoining the Illinois River. Base elevation is approximately 550 feet, rising to 640 feet as you leave the bottomlands. Surrounding lands are gently rolling. Potable water is obtained from wells 100 to 200 feet deep.

CLIMATE

Average annual percipitation is 32-34 inches; winds prevail from the southwest; inversions are infrequent.

Asarco Lead Smelter, Glover, Missouri

GENERAL INFORMATION

Glover is located in the "lead belt" of southeastern Missouri (Iron County) on State Road 49. The Asarco smelter is the only significant source of industrial emissions within a 10 mile radius. Land use in the general vicinity of the smelter is as follows:

1 mile radius:	75% timber 25% pasture
5-10 mile radius:	90% timber 10% pasture

RANGE/PASTURE RESOURCES

Pastures in the area are stocked with beef cattle at a rate of five acres per cow-year. Tall fescue (*Festuca arundinacea*) is the major forage species, with orchardgrass (*Dactylis glomerata*) and various native wild grasses being of less importance. Small amounts of woodland grazing also occur. A small population of recreational horses are found in the area. Aside from SO_2 leaf kills on Taum Sauk Mountain, two miles north of the smelter (affecting pines and deciduous species), no damage to vegetation has been reported due to the smelter (Wagner, 1975). One horse death occurred several years ago; however, the cause of death was not verified (Haasis, 1975).

FORESTRY RESOURCE

The area is forested mostly with oak-hickories with some shortleaf pine. The oak-hickory group is important commercially.

AQUATIC/FISHERY RESOURCE

Big Creek, barely a perennial stream, runs within 300 to 400 yards of the smelter. No other significant aquatic resources occur in the area.

GEOHYDROLOGY

The smelter is located in a narrow valley about 500 yards wide, which has a very gradual slope (3-5%) in an upstream/downstream direction. Elevation of the valley is approximately 850 feet. Steep topography occurs on either side of the valley, reaching heights of 1550 feet. Taum Sauk Mountain, two miles north of the smelter, has an elevation of 1772 feet, and other 1500 to 1600 foot peaks are scattered throughout the 10 mile area. Potable water for Glover is supplied through wells, the depth of groundwater being between 30 and 100 feet.

CLIMATE

Annual precipitation averages 42 inches, with July through September being the dry months. Winds are variable, generally coming from the southwest. Inversions occur occasionally.

Asarco Lead Smelter, East Helena, Montana

GENERAL INFORMATION

Located in the Rocky Mountains of west central Montana, East Helena is services by U.S. 12. Other sources of industrial emission in the area are Anaconda zinc recovery plant (within one mile of this smelter), a paint pigment plant, and a cement plant several miles southwest of Helena. Land use in the vicinity of the Asarco smelter is as follows:

1 mile radius: 4% roads
2% water
16% urban
78% agriculture

5 mile radius: 3% roads
<1% water
5% urban
92% agriculture

10 mile radius: 2% roads
3% water
3% urban
78% agriculture
14% forestland

Agriculture includes both rangeland and cultivated areas, with range accounting for roughly 60 percent of the total agricultural acreage.

AGRICULTURAL RESOURCES

The following crops are planted annually within the Helena Valley (EPA, 1972):

wheat/barley -- 20,000 acres
improved pasture -- 3000 acres
range -- 200,000 acres
alfalfa -- 4000 acres
corn, oats, potatoes -- 200 acres

The Helena Valley Environmental Pollution Study (EPA, 1972) reported the following:

1) A 15 percent reduction in vegetative growth rate in the vicinity of the smelter;

2) sulfur dioxide leaf damage to crops within one mile of the smelter;

3) potentially toxic levels of Cd and Pb in vegetables grown in the valley; and

4) tolerable levels of As and Zn in vegetables and other crops grown within a four mile radius of the smelter.

Arsenic levels in these vegetables and crops (wet weight basis) were as follows:

-pasture grass, barley straw, and alfalfa	0.4 to 14 ppm
-barley, wheat, and oat kernels	0.05 to 0.9 ppm
-onion, lettuce, carrot, and cabbage	0.9 to 3 ppm
-apple, beet, kohlrabi, potato, radish, rutabaga, string beans, and garden peas	0.05 to 0.5 ppm

RANGE/PASTURE RESOURCES

200,000 acres of range and 3000 acres of improved pasture occur in the valley. Stocking rates for range and irrigated pasture are one-half AUM per acre and one to seven AUM per acre, respectively. Sheep may not occur within the 10 mile radius, and horse raising has not been feasible near the smelter for several decades (EPA, 1972). Pastures are usually hayed once or twice each year before livestock are put on them for grazing. Improved pasture species are: Russian wild rye (*Elymus (giganteus)*), alfalfa, and various grasses. Of lesser importance is timothy (*Phleum pratense*), orchardgrass, and smooth brome (*Bromus inermis*). Principal range species are: bluebunch wheatgrass (*Agropyron spicatum*), western wheatgrass (*Apropyron smithii*), rough fescue (*Festuca scabrella*), thickspike wheatgrass (*Agropyron dasystachyum*), and blue brome (*Bromus* sp.).

The levels of As detected in the hair of horses pastured near the smelter were indicative of As exposure; however, the toxicological significance of these levels was unclear (EPA, 1972). A horse which died from "smoked" horse syndrome had levels of Pb and/or Cd associated with chronic exposure. This horse also suffered from pneumonia and/or heart disease primary or secondary to heavy metal exposure. Livestock products produced within two miles of the smelter were found to contain safe As levels (rabbit muscle, 0.6 ppm; beef liver, 0.2 ppm; while chicken muscle, beef muscle, whole milk, and sausage all contained a trace or less).

FORRESTRY RESOURCES

Principal species are Douglas fir, lodgepole pine, ponderosa pine, quaking aspen, and cottonwoods. SO_2 damage to pine seedlings has been noted up to four miles south of the East Helena complex (EPA, 1972).

AQUATIC/FISHERY RESOURCES

Prickly Pear Creek is 2.5 miles northwest of East Helena, and Lake Helena is located 10 miles northeast of East Helena. Recreational fishing does occur in these water bodies. Surface waters in Prickly Pear Creek contained 0.01 mg/l As, while water collected from the Missouri River at the city water intake contained 0.02 mg/l As. The Public Health Drinking Water Standard for As is 0.01 mg/l As. The levels of Zn, Cd, and Pb were below the Public Health Drinking Water Standards (EPA, 1972).

GEOHYDROLOGY

The Helena Valley is 25 miles wide in a north/south direction and 35 miles long in an east/west direction. The elevation of East Helena is 3900 feet, and most of the town is more or less on an (old) floodplain. Mountains rise to 7000 feet and above all around the valley. The smelter is located on a small hill within the valley and is just south of the town. The smelter is above a creek, and there are settling ponds in the area. The source of potable water for the area is the Missouri River.

CLIMATE

Each year 10 to 30 inches of precipitation fall, mostly from April to July. Strong and persistant temperature inversions are frequent.

Missouri Lead Operating Company Smelter, Boss, Missouri

GENERAL INFORMATION

The MLOC lead smelter is located approximately two miles south of Boss (Dent County) on State Road 32. It is a "trailer" town of approximately 300 people. There are no other significant emission sources in the area. Land use in the vicinity of the smelter is as follows:

1 mile radius: 100% timber (less than 1% urban/industrial/residential)

5 mile radius: 20% pasture
80% timber

10 mile radius: 20% pasture
80% timber

AGRICULTURAL RESOURCES

A very small amount of row crop agriculture is carried on in the region--mostly corn and wheat. SO_2 damage has occurred on home gardens during smelter malfunctions (Robinson, 1975).

RANGE/PASTURE RESOURCES

Beef cattle are raised on improved pasture as well as in 80% of the oak/hickory woodlands. Stocking rates in low management pastures are six to seven acres per cow/year; on high management pastures they are three to four AU/year. Most pastures are located on cleared bottomland drainage areas. Some hog production occurs in oak/hickory woodlands. Important forage species are fescue (*Festuca* sp.), *Lespedeza*, red clover (*Trifolium pratense*), medino clover (*Trifolium* sp.), and small amounts of alfalfa. The smelter is not known to have had any adverse effects upon livestock (Robinson, 1975). Most pastures/open lands are located west of the smelter, and are not usually downwind from stack emissions.

FORESTRY RESOURCES

Most of the forested land in the vicinity of the smelter is in an oak/hickory association. Oaks are the most important timber species (red, scarlet, black, white), with shorleaf pine being of secondary importance. Hickories (shagbark, bitternut) are also harvested commercially, as are black walnuts. Studies of Pb in livestock and trees are reportedly being conducted by NSF/Oak Ridge Laboratory.

AQUATIC/FISHERY RESOURCES

A number of creeks occur within 10 miles of the smelter: Big Sinking Creek, Water Fork, Dry Fork (the latter two empty into Merrimac River). Two branches of Huzzah Creek occur within five miles northwest of the smelter. Loggers Lake (20 acres) occurs approximately 10 miles to the south. Fishery resources in the area are insignificant. Strother Creek comes out of smelter settling ponds, and is being monitored for water quality.

GEOHYDROLOGY

Elevations vary in the region from 1100 to 1300 feet. Topography may be described as sharp and erratic, characterized by flat ridge tops with very steep (30%) slopes. Overall elevations drop eastward from the smelter, which is located on a ridge top. Wells provide potable water, the water table being between 300 and 500 feet deep.

CLIMATE

Precipitation averages 40 inches annually. Winds prevail from the west-southwest, coming out of the northwest during cold fronts. Inversions do occur.

St. Joe Lead Smelter, Herculaneum, Missouri

GENERAL INFORMATION

The St. Joe smelter adjoins the Mississippi River in Jefferson County, Missouri and is located in Herculaneum, about 20 miles south of St. Louis. U.S. 61 is the major highway servicing the area. Other sources of industrial emissions in the area are an agrichemical plant approximately four to five miles south on the Mississippi River, Pittsburgh Plate Glass in Crystal City to the south, and a Dow Chemical plant to the north in Pevely. In addition, Utility Electric is constructing a power plant approximately 15 miles to the south on the Jefferson County line. Land use in the vicinity of the smelter is as follows:

1 mile radius: 60% urban/industrial/residential
5% cropland
15% pasture
20% woodland

5-10 mile radius: 20% urban/industrial/residential
20% cropland
25% pasture
35% woodland

AGRICULTURAL RESOURCES

Soybeans and corn are the major crops in the area, with some winter wheat and milo also being grown. Adverse effects upon crops or other vegetation have not been observed to occur due to smelter emissions (Kohne, 1975).

RANGE/PASTURE RESOURCES

Beef cattle production occupies 90% of the pastures in the general area. A few dairy farms are located near Pevely (three miles north of the smelter). Pasture grasses are predominately tall fescue and orchardgrass. Limited amounts of woodland grazing occur. No adverse effects have been observed on livestock as a result of smelter emissions (Kohne, 1975).

FORESTRY RESOURCES

There are no commercial tree farms in the area. However, oak-hickories and eastern red cedar are harvested sporadically from the area.

AQUATIC/FISHERY RESOURCES

The smelter is adjacent to the Mississippi River and also adjoins Joachim Creek, a small tributary of the river. A small dam is located on Joachim Creek for the purpose of conserving water for the smelter's use. Plattin Creek is located two miles south of the smelter, and Isle du Bois Creek is located five to six miles south. Although there have been no recent reports of effluent from the smelter, the smelter has in years past dumped "oil" directly into the river. Due to the high flow volume of the Mississippi River, no direct adverse effects were noted. Fish species taken commercially in the Mississippi River are catfish, carp, and buffalo fish.

GEOHYDROLOGY

The smelter is located in rolling river hills bordering the Mississippi River, and this rolling topography is characteristic of the 10 mile area surrounding the smelter. The smelter draws water from Joachim Creek.

Gulf Chemical and Metallurgical Tin Smelter, Texas City, Texas

The Gulf Chemical and Metallurgical Tin Smelter is located in Texas City, Texas, a generally industrialized area. The smelter presently has large Sn emissions and emits As and Mo in measurable quantities. A small amount of grazing land is located to the south of the smelter, and residential areas occur to the west and northwest. Furthermore, the smelter is located within one-half mile of Galveston Bay and there have been major discharges of heavy metals into the Bay. Adjacent to the smelter, 150 $\mu g/m^3$ As and 1500 $\mu g/m^3$ Sn have been recorded. Overall, the El Paso area probably is the worst problem area for As in Texas, although adverse effects are not presently occurring. Texas City probably has the next highest As levels, while Amarillo and Corpus Christi presently have no As problems (Price, 1975).

Domestic secondary copper smelters.

Company and Location	Production	Comments
NEW ENGLAND		
1. Mitchell Smelting Refining Company. Portland, Conn.	Small	Land use within 5 miles of Portland is primarily urban industrial, with agriculture comprising approximately 5% of the total acreage. No damage to crops, vegetation or livestock has been noted. (Cavanna, 1976)
2. North American Smelting Company. Wilmington, Del.	Moderate	The smelter is located in an industrial/port area with no agriculture within 1 mile and 10% agriculture within 5 miles. Corn and soybean are the major crops, and no smelter related damage has been noted in the area. The newest commercial fishing on the Delaware River occurs 15 miles downstream from the smelter. (Nash, 1976).
3. Bay State Refining. Chicopee Falls, Mass.	Small	Truck crops and dairy farms account for less than 10% of the land acreage in a 5 and 10 mile radius of Chicopee Falls. A small portion of the remaining land is fallow agricultural land which is no longer economically profitable to farm. The Chicopee River does not support commercial fishing. (Warren, 1976)
4. New England Smelting. West Springfield, Mass.	Small	Within 1 mile of the smelter land use is entirely residential/industrial. However, land use in the 5 mile radius includes 40% agriculture. Agricultural activities center around truck crops and dairy farms, and no damage due to smelter emissions has been noticed. No commercial fishing occurs in this portion of the Connecticut River. (Kane, 1976).

Domestic secondary copper smelters.

Company and Location	Production	Comments
NEW ENGLAND		
1. Mitchell Smelting Refining Company. Portland, Conn.	Small	Land use within 5 miles of Portland is primarily urban industrial, with agriculture comprising approximately 5% of the total acreage. No damage to crops, vegetation or livestock has been noted. (Cavanna, 1976)
2. North American Smelting Company. Wilmington, Del.	Moderate	The smelter is located in an industrial/port area with no agriculture within 1 mile and 10% agriculture within 5 miles. Corn and soybean are the major crops, and no smelter related damage has been noted in the area. The newest commercial fishing on the Delaware River occurs 15 miles downstream from the smelter. (Nash, 1976).
3. Bay State Refining. Chicopee Falls, Mass.	Small	Truck crops and dairy farms account for less than 10% of the land acreage in a 5 and 10 mile radius of Chicopee Falls. A small portion of the remaining land is fallow agricultural land which is no longer economically profitable to farm. The Chicopee River does not support commercial fishing. (Warren, 1976)
4. New England Smelting. West Springfield, Mass.	Small	Within 1 mile of the smelter land use is entirely residential/industrial. However, land use in the 5 mile radius includes 40% agriculture. Agricultural activities center around truck crops and dairy farms, and no damage due to smelter emissions has been noticed. No commercial fishing occurs in this portion of the Connecticut River. (Kane, 1976).

Company and Location	Production	Comments
5. Richards Corporation. Malden, Mass.	Small	No significant agriculture occurs within 10 miles of Malden. (Williams, 1976)
6. Amax. Carteret, N.J.	Large	No significant agriculture occurs within 10 miles of Carteret. (Powley, 1976)
7. Barth Smelting and Refining Newark, N.J.	Large	Land-use within 10 miles of Newark is all urban/industrial. (Powley, 1976)
8. Kearney Smelting and Refining Company. Kearney, N.J.	-	Land-use within 10 miles of Kearney is all urban/industrial. (Powley, 1976)
9. Belmont Smelting. Brooklyn, N.Y.	Small	All points with 5 miles of Brooklyn are heavily urbanized/industrialized.
10. Nassau Smelting and Refining. Tottenville, N.Y.	Large	Tottenville is located approximately 5 miles south of the Amax smelter in Carteret. No significant agriculture occurs within a 10 mile radius of Tottenville. (Powley, 1976)
11. Paragon Smelters. Long Island, N.Y.	Very Small	The location of the smelter is not definitely known; a Paragon Corporation is located in Brooklyn, the only "Paragon" on Long Island. No significant agriculture occurs within 5 miles of Brooklyn.
12. Colonial Metals. Columbia, Pa.	Moderate	Although no agriculture occurs within 1 mile of the smelter, land use within 5 and 10 miles of the smelter is 70-75% agriculture. The smelter is located in an area with other significant industrial emission sources, but no damage to crops, forage or livestock has been noted. Corn is the major crop, with pasture occupying the non-cultivated agricultural lands. No commercial fishing occurs in the area. (Hackman, 1976; Conn, 1976; Behling, 1976)

Company and Location	Production	Comments
13. Franklin Smelting and Refining. Philadelphia, Pa.	Moderate	This smelter is located in the northeastern portion of the city, and no agricultural lands occur within a 5 mile radius. (Glacer, 1976)
14. George Sall Metals. Philadelphia, Pa.	Small	This smelter was closed down in 1974 due to business problems. No agricultural lands occur within 5 miles of the smelter. (Glacer, 1976)
15. Metal Bank of America, Philadelphia, Pa.	-	There are no agricultural lands within 5 miles of the smelter. (Glacer, 1976)
16. Metallurgical Production Company. Philadelphia, Pa.	Small	This smelter was closed in the late 1960's or early 1970's. No agricultural lands occur within 5 miles of the smelter. (Glacer, 1976)
17. Reading Metals Refining. Reading, Pa.	Moderate	Land use within 1 mile of the smelter includes 35% cropland and 35% pasture. Cropland and pasture comprise 25% each of the 5 mile radius and 20% each of the 10 mile radius. Corn and small grains are the major crops. No damage to crops or livestock has been noted in the area. (Judy, 1976)
18. Roessing Bronze Co. Mars, Pa.	Moderate	Lands in the vicinity of the smelter are generally 40% agricultural, 45% woodland, and 15% rural/residential. Agricultural activities include dairying and grain farming. Litigation has occurred over damage to ornamental vegetation in a nearby residence. An analysis of heavy metal fallout from Roessing's emissions yielded the following (in micrograms/gram): Mg-1200, Fe-328, Cu-400, Al-278, Zn-800 (Pennsylvania State University, 1976). Other industries with significant emissions occur within 5 miles of the smelter. (Breisch, 1976; Kapp, 1976)

Company and Location	Production	Comments
19. Sitkin Smelting and Refining Company. Lewistown, Pa.	Moderate	Located in a mountainous area, land use within a 1, 5 and 10 mile radius includes 40, 20, and 50% agriculture, respectively. Agricultural lands are approximately 20% pasture and 80% cropland, with corn, hay, and small grains being the principal crops. No smelter-related damage to crops or livestock has been noted in the area. A steel fabrication plant occurs within 5 miles of the smelter.
GREAT LAKES REGION & MIDWEST		
1. Benjamin Harris. Chicago Heights, Ill.	Small	Land use within 1 mile of the smelter is entirely industrial/residential; however, land use within a 6 mile radius is roughly 65% agricultural. Major crops are corn and soybeans, and no damage to crops has been noted in the vicinity of the smelter. Other industries with significant emissions are located in the vicinity of the smelter. (Mariner, 1976)
2. Cerro Copper and Brass. Sauget, Ill.	Large	Located in a heavily industrialized area adjacent to the Mississippi River, land use within 1 mile of the smelter is completely industrial/residential. Within 5 and 10 miles of the smelter, agricultural land use is 20 and 30%, respectively. Most farming occurs in bottomlands safeguarded by flood protection levees, with sweet corn, wheat, and soybeans being the major crops. This smelter is located within 1 mile of the Amax primary zinc smelter at Sauget. (Hoekstra, 1976; Quandt, 1976; Harryman, 1976; and McQueen, 1976)

Company and Location	Production	Comments
3. Chemetco. Alton, Ill.	Moderate	Agricultural lands account for 10 and 30% of the total acreage within 5 and 10 miles of the smelter, respectively. Located in a heavily industrialized area of refineries, paper mills, and fiberglass plants, the smelter is also within 5 miles of the Olin-Winchester BB plant, which emits significant quantities of Pb and As. (McQueen, 1976)
4. North Chicago Refiners & Smelters. North Chicago, Ill.	Moderate	No significant agriculture occurs within 10 miles of the smelter. (Nargang, 1976)
5. Interstate Smelting and Refining. Chicago, Ill.	Small	No significant agriculture occurs within 5 miles of the smelter. (Thorp, 1976)
6. H. Kramer and Company. Chicago, Ill.	-	No significant agriculture occurs within 5 miles of the smelter. (Thorp, 1976)
7. R. Lavin and Sons. Chicago, Ill.	Moderate	No significant agriculture occurs within 5 miles of the smelter. (Thorp, 1976)
8. S.P. Metals. Chicago, Ill.	Small	No significant agriculture occurs within 5 miles of the smelter. (Thorp, 1976)
9. Federated Metals (ASARCO). Whiting, Ind.	Moderate	No significant agriculture occurs within 10 miles of the smelter. (Broadstreet, 1976)
10. Mishawaka Brass Manufacturing Company. Mishawaka, Ind.	Small	Land use within 1 mile of the smelter is 60% urban and 40% agricultural. Agricultural land use within 5 and 10 miles of the smelter is 55 and 60% cropland, respectively. Major crops on non-muck soils are corn, soybeans, and wheat. Muck soils occur within 7 miles of the smelter, and these are used to produce a variety of truck crops. No smelter-induced damage to vegetation or crops has been noted. (Stonebraker, 1976; Lauster, 1976; Purdue University Cooperative Extension Service, 1971)

Company and Location	Production	Comments
11. South Bend Smelting Company South Bend, Ind.	Small	Located 8 1/2 miles west of the Mishawaka smelter, land use within 1 mile of the South Bend smelter is 100% urban/industrial. Agricultural lands comprise 25 and 50% of the acreage within 5 and 10 miles of the smelter, respectively. Muck soils occur southwest of the smelter, with production on these soils beginning within 5 miles. Crops grown in the region are corn, soybeans, wheat, and a variety of truck crops. (Stonebraker, 1976; Lauster, 1976; Purdue University Cooperative Extension Service, 1971)
12. S-G Corporation, Inc. Kansas City, Kansas	Small	No agricultural land use occurs within 1 mile of the smelter, with 5 and 8% agricultural lands occurring within the 5 and 10 radius, respectively. Primary crops are corn, soybeans, milo, and wheat. (Ritter, 1976)
13. G. Avril. Cincinnati, Ohio	Small	Minor amounts of field and greenhouse crop production occur within 10 miles of the smelter. A lead isotope manufacturing plant is located 10 miles northwest of the smelter. (Cummings, 1976)
14. Federal Metal Company. Bedford, Ohio	Small	Farmland and non-cultivated open land account for 10, 15, and 25% of the acreage within 1, 3, and 5 miles of the smelter, respectively. Other industrial emission sources are common; the I. Schuman and Sons BB smelter being located within 1/2 mile of the Federal Metal Company smelter. (Anderson, 1976)
15. I. Schuman and Sons. Cleveland, Ohio	Moderate	See Federal Metal Company, Bedford, Ohio.
16. River Smelting and Refining. Cleveland, Ohio	-	No significant agriculture occurs within 5 miles of the smelter. (Anderson, 1976)

Company and Location	Production	Comments
17. Libberman-Gittlen Metals Company. Grand Rapids, Mich.	Small	Less than .5% agriculture within 5 miles of the smelter. 20% agriculture occurs within 10 miles of the smelter but no smelter-induced damage to crops has been noted in the area. (LeBlanc, 1976)
SOUTHEAST		
1. W.J. Bullock. Birmingham, Ala.	Small	No agricultural lands occur within 10 miles of the smelter. (King, 1976)
2. Lee Brothers Foundry Company. Anniston, Ala.	Small	Land use within 1 mile of the smelter includes 16% pasture and 4% cropland. Within 5 and 10 miles of the smelter 24/6% and 28/7% of pastures/cropland occur, respectively. No other industries are located in the vicinity of the smelter, and no damage to crops or livestock has been noted in the area. (DeBardeleben, 1976)
3. Copper Division, Southwire. Carrollton, Ga.	Moderate	No agricultural land use occurs within 1 mile of the smelter. Land use within 5 and 10 miles of the smelter is 15 and 10% agricultural, respectively. Major crops are soybeans and corn. The Southwire complex is the only significant source of industrial emissions in the area. (Jordan, 1976)
4. Federated Metals (ASARCO). Houston, Tx.	Small	No significant agriculture occurs within 5 miles of the smelter. Land use within 10 miles includes 10% pasture/range and 3% irrigated rice land. The smelter is located in an industrial area, and no damage to vegetation or livestock has been noted. (Brown, 1976)

Company and Location	Production	Comments
WEST		
1. Federated Metals (ASARCO). San Francisco, Calif.	Moderate	No information available.
2. H. Kramer and Company. El Segundo, Calif.	-	No significant agricultural or range resources within 10 miles of the smelter. (Loverde, 1976)
3. H. Kramer and Company. Chino, Calif.	-	Land use within 5 miles of Chino is 50% agricultural and 50% urban/industrial. Agricultural lands occupy 25% of the area within 10 miles. Agricultural lands are predominately pastures for dairying, but some production of alfalfa and row crops does occur. No smelter-induced damage upon vegetation or livestock has been noted in the area. (Hampton, 1976)
4. Mackay, B.R. and Sons, Inc. Salt Lake City, Utah	Small	Agricultural lands and rangelands account for 30 and 20% of the acreage within 1 mile of the smelter. Agricultural/range lands occupy 20/15% and 20/20% of the area within 5 and 10 miles of the smelter, respectively. Agricultural lands are planted primarily to forage crops. A Kennecott primary copper smelter is located 10 miles to the west. (Ramses, 1976)

APPENDIX B

Bureau of Mines
Lists of Existing and Closed Smelters

Zinc Smelters Closed Since 1925

	County	City	State	Date closed
Tulsa Fuel Mfg. Co	Tulsa	Collinsville	Oklahoma	1925
American Zinc Co. of Illinois	Montgomery	Hillsboro	Illinois	1926
National Zinc Co	Sangamon	Springfield	---do----	1926
United States Zinc	Okmulgee	Henryetta	Oklahoma	1927
Fort Smith Spelter Co	Sebastian	Ft. Smith	Arkansas	1927
Eagle-Picher Lead	Montgomery	Hillsboro	Illinois	1927
Amalgamated Lead/Zinc	Okmulgee	Henryetta	Oklahoma	1927
Blackwell Zinc	Kay	Blackwell	---do----	1928
Grasselli Chemical Co	Harrison	Clarksburg	W. Virginia	1928
Weir Smelting Co	Montgomery	Caney	Kansas	1929
Edgar Zinc Co. 1/	---do------	Cherryvale	---do----	1934
United States Zinc Co		Kusa	Oklahoma	1934
Matthiessen & Hegeler Co	Vigo	Terre Haute	Indiana	1937
Quinton Spelter Co	Pittsburg	Quinton	Oklahoma	1938
Illinois Zinc	La Salle	Peru	Illinois	1939
Arkansas Zinc & Smelting 2/	Crawford	Van Buren	Arkansas	1947
Hegeler Zinc Co	Vermilion	Danville	Illinois	1947
American Zinc & Chemical	Washington	Langeloth	Pennsylvania	1947
United Zinc Smelting Corp	Marshall	Moundsville	W. Virginia	1948
American Steel & Wire Co	Washington	Donora	Pennsylvania	1957
American Zinc Co. of Illinois	St. Clair	E. St. Louis	Illinois	1958
Matthiessen & Hegeler Co	La Salle	La Salle	---do----	1961
Athletic Mining and Smelting	Sebastian	Ft. Smith	Arkansas	1963
Eagle-Picher Lead Co	Okmulgee	Henryetta	Oklahoma	1969
New Jersey Zinc Co	Bureau	Depue	Illinois	1971
Matthiessen & Hegeler Zinc	Harrison	Meadowbrook	W. Virginia	1971
ASARCO Incorporated	Moore	Dumas	Texas	1971
The Anaconda Company	Cascade	Great Falls	Montana	1972
Amax Zinc	Kay	Blackwell	Oklahoma	1973
The Anaconda Company	Deer Lodge	Anaconda	Montana	1973
ASARCO Incorporated	Potter	Amarillo	Texas	1975

1/ American Steel & Wire Co.
2/ Falcon Zinc, Eagle Picher.

Secondary Zinc Smelters Currently in Operation

	County	City	State	Startup date
W. J. Bullock	Jefferson	Fairfield	Alabama	1939
Gulf Reduction	Harris	Houston	Texas	1957
Hugo-Neu Proler	Los Angeles	Terminal Island	California	1968
Pacific Smelting	---do-------	Torrance	---do------	1/1929
Proler International	Harris	Houston	Texas	2/1964
Prolerized Schiabo-Neu Co	Hudson	Jersey City	New Jersey	1974

1/ Present owner started production in 1943.
2/ Shut down in 1973, but started again in 1974.

Copper Smelters Closed Since 1925
(Plants that treated copper ore, concentrates, and other copper materials)

	County	City	State	Capacity (Tons of charge)	Date closed
Afterthought Copper Co	Shasta	Ingot	California	80,000	1925
The Anaconda Company	Cascade	Great Falls	Montana	800,000	1924
Arizona Smelting and Power Co	Tucson	Benson	Arizona	54,000	1926
ASARCO Incorporated	Salt Lake	Garfield	Utah	1,440,000	1958
Do	Douglas	Omaha	Nebraska	--	1926
Do	Middlesex	Perth Amboy	New Jersey	101,000	1930
Do	Lake	Leadville	Colorado	120,000	1936
Calaveras Copper Co	Calaveras	Copperopolis	California	110,000	1934
Calumet & Arizona Mining Co	Cochise	Douglas	Arizona	970,000	1930
Consolidated Arizona Smelting Co	Yavapai	Homboldt	---do---	--	1933
Douglas Mountain Mines Co		Near Sunbeam	Colorado	11,000	1922
Ducktown Sulphur & Iron Co	Polk	Isabella	Tennessee	320,000	1934
East Butte Copper Mining Co	Silver Bow	Butte	Montana	230,000	1930
International Smelting Co. (Inspiration Consolidated Copper Co.)	Tooele	Tooele	Utah	600,000	1950
Magma Copper Co	Pinal	Superior	Arizona	150,000	1971
Mason Valley Mines Co	Lyon	Thompson	Nevada	400,000	1930
Missouri Cobalt Co	Madison	Fredericktown	Missouri	40,000	1926
Mountain Copper Co. Ltd	Contra Costa	Martinez	California	105,000	1926
Nichols Copper Co. (Phelps Dodge Corp.)	Queens	Laurel Hill, L.I.	New York	200,000	1962
Norfolk Smelting Co	Portsmouth	West Norfolk	Virginia	94,500	1929
Old Dominion Co	Gila	Globe	Arizona	308,000	1932
Ouray Smelting and Refining Co	Ouray	Ouray	Colorado	198,000	1927
Penn Mining Co	Calaveras	Campo Seco	California	91,000	1926
Sumpter Valley Smelter	Baker	Sumpter	Oregon	70,000	1926
U.S. Smelting Refining and Mining Co		Kennett	California	420,000	1925
United Verde Copper Co. (Phelps Dodge Corp.)	Yavapai	Clarkdale	Arizona	1,400,000	1950
United Verde Extension Mining Co	---do---	Clemenceau	---do---	275,000	1937
Western Copper Mining Co		Reiter	Washington	25,000	1926
Western Smelting and Power Co	Park	Cooke	Montana	109,500	1930
LAKE PLANTS					
Calumet and Hecla Mining Co	Houghton	Hubbell	Michigan	225,000	1968
Lake Superior Smelting Co	---do---	Dollar Bay	---do---	125,000	1929
Michigan Smelting Co	---do---	Houghton	---do---	130,000	1952
Quincy Smelting Works	---do---	Hancock	---do---	55,000	1967

SECONDARY SMELTERS TREATING COPPER MATERIALS

ASARCO Incorporated, Federated Metals Div., 120 Broadway, New York, NY 10005
San Francisco, CA
Whiting, IN
Newark, NJ
Houston, TX

Apex Smelting Co., 6700 Grant Avenue, Cleveland, OH 44105

The G. A. Avril Co., Brass & Bronze Ingot Div., 66 Winton Place Sta.,
4445 Kings Run Drive, Cincinnati, OH 45232

Barth Smelting Corp., 99-129 Chapel Street, Newark, NJ 07105

Bay State Refining Co., Inc., 8 Montgomery Street, Chicopee, MA 01021

Joseph Behr & Sons, Inc., 1100 Seminary Street, Rockford, IL 61105

Belmont Sm. & Rfg. Wks., Inc., 330 Belmont Avenue, Brooklyn, NY 11207

Brush Wellman, Inc., 17876 St. Clair Avenue, Cleveland, OH 44110
Elmore, OH

W. J. Bullock, Inc., Box 539, Fairfield, AL 35064

Chemico Metals Corp., P.O. Box 187, Alton, IL 62002

Colonial Metals Co., P.O. Box 311, Second & Linden Sts., Columbia, PA 17512

Federal Metal Co., 7250 Division Street, Bedford, OH 44146

Handy & Harman, Attleboro Rfg. Div., Attleboro, MA 02703

Benjamin Harris & Co., 11th & State Sts., Chicago Heights, IL 60412

Henning Bros. & Smith, Inc., 91 Scott Avenue, Brooklyn, NY 11237

Hewitt Metals Corp., 12th & Stanley Avenue, Detroit, MI 48208

Imperial Smelting Corp., 1031 E 103rd Street, Chicago, IL 60628

Interstate Sm. & Rfg. Co., 9631 S Torrence Avenue, Chicago, IL 60617

N. Kamenske & Co., Inc., 5 Otterson Court, Nashua, NJ 03060

Kawecki Berylco Inds., Inc., Alloy Div., P.O. Box 1462, Reading, PA 19603

Kearny Sm. & Rfg. Corp., 936 Harrison Ave., Kearny, NJ 07029

Morris P. Kirk & Son, Div. of NL Industries, Inc., 2717 S Indiana St.,
Los Angeles, CA 90023

H. Kramer & Co., P.O. Box 7, No. 1 Chapman Way, El Segundo, CA 90246

H. Kramer & Co., 1339-1345 W 21st Street, Chicago, IL 60608

R. Lavin & Sons, Inc., 3426 S Kedzie Avenue, Chicago, IL 60623

Lee Bros. Corp., P.O. Box 1229, Anniston, AL 36201

Mercer Alloys Corp., P.O. Box 511, Greenville, PA 16125

Metallurgical Products Co., 35th & Moore Streets, Philadelphia, PA 19145

Milward Alloys, Inc., P.O. Box 336, N Transit & Mill St., Lockport, NY 14094

NL Industries, Inc., 111 Broadway, New York, NY 10006
Perth Amboy, NJ

NL Industries, Inc., 4670 Werk Road, Cincinnati, OH 45211

NL Industries, Inc., 1776 Columbus Road, Cleveland, OH 44113
Pittsburgh, PA

NL Industries, Inc., 1015 Locust Street, St. Louis, MO 63101
Dallas, TX

Nassau Recycle Corp., 286 Richmond Valley Road, Tottenville, NY 10307

New England Sm. Works, Inc., 502 Union Street, W Springfield, MA 01089

North American Smelting Co., Marine Terminal, Wilmington, DE 19899

North Chicago Rfg. & Sm. Inc., 2028 S Sheridan Road, N Chicago, IL 60064

River Sm. & Rfg. Co., P.O. Box 5755, Cleveland, OH 44101

Rochester Sm. & Rfg. Co., Inc., P.O. Box 547, 26 Sherer Street,
Rochester, NY 14611

Roessing Bronze Co., P.O. Box 60, Mars, PA 16046

S-G Metals Inds., Inc., 2nd & Riverview, Kansas City, KS 66118

Geo. Sall Metals Co., Inc., 2255 E Butler Street, Philadelphia, PA 19137

I. Schumann & Co., 22500 Alexander Road, Bedford, OH 44146

Sipi Metals Corp., 1720 N Elston Avenue, Chicago, IL 60622

Sitkin Sm. & Rfg. Inc., P.O. Box 708, Lewistown, PA 17044

South Bend Sm. & Rfg. Co., 1610 Circle Avenue, S Bend, IN 46621

Specialloy Inc., 4025 S Keeler Avenue, Chicago, IL 60632

Lead Smelters Closed Since 1925

	County	City	State	Capacity	Date closed
ASARCO Incorporated---------------------	La Plata	Durango	Colorado	120,000	1940
Do-------------------------------	Lake	Leadville	---do-----	180,000	1961
Do-------------------------------	Salt Lake	Murray	Utah	150,000	1949
Do 1/----------------------------	Douglas	Omaha	Nebraska	38,000	1934
Do 1/----------------------------	Middlesex	Perth Amboy	New Jersey	165,000	1934
Do-------------------------------	Contra Costa	Selby	California	216,000	1970
Bullshead Mining and Smelting Co---------	Elko	Spruce Mtn.	Nevada	11,000	1925
Eagle-Picher Lead Co--------------------	Cherokee	Galena	Kansas	10,000	1956
Federal Lead Co. 2/- ------------------	Madison	Alton	Illinois	128,000	1959
Granby Mining and Smelting Co. 3/-------	Newton	Granby	Missouri	24,000	1942
International Smelting and Refining Co--	Tooele	Tooele	Utah	300,000	1971
Louisiana Consolidated Smelting Co------	Nye	Tonopah	Nevada	30,000	1925
Ontario Smelting Co. 4/-----------------	Pollanwatomie	S. Louis	Oklahoma	30,000	1927
Phelps Dodge Corp-----------------------	Cochise	Douglas	Arizona	77,000	1931
St. Louis Smelting and Refining Co------	Madison	Collinsville	Illinois	78,000	1934
U.S. Smelting, Refining & Mining Co-----	Salt Lake	Midvale	Utah	250,000	1958
United States Mining and Refining Co----	Essex	Newark	New Jersey	180,000	1935

1/ 1934 - smelters dismantled, refinery only.
2/ 1926 - ASARCO Incorporated.
3/ 1921 - American Zinc, Lead & Smelting Co.
4/ 1923 - leased to Eagle-Picher Lead Co.

Major Secondary Lead Smelting Companies Reporting
to the Bureau of Mines

Company	Plant
ASARCO Incorporated (including Federated Metals Div.)	San Francisco, CA, Whiting, IN, Omaha, NE, Newark, NJ, Houston, TX.
Chloride Metals, Div. of Contract Manufacturers, Inc	Tampa, FL, Columbus, GA Florence, MS.
East Penn Mfg. Co	Lyons Station, PA.
General Battery Corp	Reading, PA.
Gopher Smelting & Refining Co	St. Paul, MN.
Gould, Inc	Omaha, NE, Philadelphia, PA.
Nassau Recycle Corp	Tottenville, NY.
NL Industries, Inc. (including Bearings Magnus Div.)	Los Angeles, CA, Atlanta, GA Chicago, Granite City, and McCook, IL Beach Grove, IN, St. Louis Park, MN St. Louis, MO, Fremont, NE Pedricktown, NJ, Cincinnati and Cleveland, OH, Portland, OR Dallas and Houston, TX.
RSR Corp. (including Murph-Murdock Div. and Quemetco Div.)	City of Industry, CA Indianapolis, IN, Middletown, NY Dallas, TX, Seattle, WA.
Richardson Graphics	Philadelphia, PA.
Schuylkill Metal Corporation	Baton Rouge, LA.
Seitzinger's Inc	Atlanta, GA.
U.S.S. Lead Refinery, Inc	East Chicago, IN.
Hyman Viener, and Sons	Richmond, VA.
Willard Smelting Company	Charlotte, NC.

Startup dates not available.

Plants Treating Tin Materials, Closed Since 1925

	County	City	State	Date closed
Metal & Thermit Corp----------------------	Union	Rahway	New Jersey	1942
Franklin Smelting & Refining Co-----------	Philadelphia	Philadelphia	Pennsylvania	1942
American Metal Co-------------------------	Middlesex	Carteret	New Jersey	1943
Phelps Dodge Refining Corp----------------	Queens	Laurel Hill, L.I.	New York	1943
Nassau Smelting & Refining Co-------------	Staten Island	Tottenville	New York	1945
ASARCO Incorporated-----------------------	Middlesex	Perth Amboy	New Jersey	1946
Vulcan Detinning Co-----------------------	---do-----	Sewaren	---do------	1951

There are no secondary tin smelters in the United States. Copper and lead secondary smelters recover tin from scrap.

GOLD

Gold usually in a flotation concentrate, is treated together with other base metals, particularly copper, at base metal smelters, hence, there are no gold smelters, as such.

A few mine operators produce a gold-silver bullion product from cyanide precipitates by fluxing, melting, and refining in relatively small furnaces. The Bureau of Mines has no record of these operations since, in the past, statistics on processed gold were collected by the Office of Domestic Gold and Silver Operations in the Department of the Treasury. Possibly, Treasury would have historical information available on these small furnace operations, but the pollution potentials would seem limited.

Companies currently operating cyanide precipitate reduction plants of any significance are Homestake Mining Co. at Lead, Lawrence Co., South Dakota; Carlin Gold Mining Co. near Carlin, Eureka Co., Nevada; and Cortez Gold Mines, near Cortez, Lander Co., Nevada. The Cortez operations are about to close. The Homestake operations date back to the late 1800's, the Carlin operations began in 1965, and the Cortez operations began in 1969.

Roasting of gold ores as a means of increasing recovery has been practiced at mines with refractory ores, but no records have been collected on this. One of the operations where roasting was significant because of the large amounts of arsenic in the ore was the Getchell mine in Humboldt Co., Nevada. The nearest city is Winnemucca. The last year of production at the Getchell was 1967 and the plant has been dismantled. Exploration has been conducted at the site recently and consideration is being given to renewed operations.